Global Innovation Hotspots

Singapore's innovation and entrepreneurship ecosystem

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Global Innovation Hotspots

Singapore's innovation and entrepreneurship ecosystem

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Summary

Since its political independence in 1965, Singapore has achieved rapid economic growth and transformed itself into a major global financial, business and transport/information technology (IT) hub, with GDP per capita ranking among the highest in the world since the beginning of this decade. While the first three decades of Singapore's rapid economic growth have been based largely on a strategy to attract and leverage global multinational corporations (MNCs) to create increasingly higher value-adding economic activities, the last 25 years have witnessed an increasing shift toward promoting technological innovation and entrepreneurship, and the building of a vibrant innovation and entrepreneurship ecosystem that supports several major clusters of innovation, including medtech, smart urban mobility/infrastructure and internet/mobile e-commerce. More recently, the city-state has also been seeking to accelerate the commercialization of a wider range of deep technologies from universities and public research labs, including artificial intelligence (AI), advanced materials and fintech.

This report consists of two parts. Part A traces the dynamic evolution of Singapore's innovation and entrepreneurship ecosystem over time and the changing mix of public policies that have shaped that evolution. Building on research work on the earlier phases of development of Singapore's innovation and entrepreneurship ecosystem (Wong, 2001; Wong, 2006; Wong and Singh, 2008; Wong *et al*., 2017; Wong, 2019), this part of the report brings the analysis of Singapore's innovation ecosystem development trends up to the end of 2020. In Part B, we present a more in-depth analysis of the changing pattern of innovation among the key innovation actor groups in Singapore – local enterprises, local universities and public research institutes, and foreign firms with innovation activities in Singapore – using a database of patents granted to inventors in Singapore for the period 2000–2020. Using the same patent database, we also examined the changing pattern of international links between Singapore-based innovation actors and leading innovative regions overseas, including the leading innovation hotspots identified by WIPO.
Keywords: innovation, entrepreneurship, Singapore, public policy, ecosystem, patent data analysis

Part A: Singapore’s innovation ecosystem development

1 Introduction

Since its political independence in 1965, the small island-state of Singapore has achieved rapid economic growth and transformed itself into a major global financial, business and transport/information technology (IT) hub. In terms of gross domestic product (GDP) per capita, Singapore surpassed Japan in 2010 and caught up with the United States of America (US) in the mid-2010s (World Bank, 2018). Despite slowing growth in recent years, Singapore’s GDP (purchasing power parity, PPP) per capita in 2021 still ranked as the second-highest in the world (IMF, 2021).

The rapid economic development of Singapore from developing to developed country in less than four decades was achieved through a consistent public policy focus on attracting and leveraging direct foreign investments from global multinational corporations (MNCs) to achieve continuous technological capability upgrading and productivity growth (Wong, 2003). By encouraging global MNCs to transfer increasingly more advanced technologies and know-how to their subsidiary operations in the city-state, and by investing heavily in education and on-the-job training to enable the domestic workforce to rapidly absorb and diffuse new technologies, Singapore has been able to achieve rapid technological catch-up, industrial upgrading and productivity improvement. This is despite not having substantially invested in public research and development (R&D) to develop indigenous technological innovation capabilities until late in its economic development, compared with Japan, Taiwan Province of China and the Republic of Korea; indeed, even today Singapore does not have a science and technology ministry, and science, technology and innovation (STI) policies are implemented via multiple ministries/agencies. Moreover, much of the public R&D spending has, until recently, been directed at the innovation needs of the global MNCs and some of the large government-linked corporations in strategic sectors, with somewhat less going to local small and medium-sized enterprises – in contrast to, for example, the priorities followed in Taiwan Province of China (Wong, 2019).

While this unique economic development model – an open economy framework combined with strong state intervention – has been the basis for Singapore’s remarkable economic success, concerns have been growing among the city-state’s intelligentsia and political leadership that this development model needs to be significantly changed for the city-state to continue to prosper in the new millennium. With its high developed-country costs, Singapore now needs to compete close to the technological frontier of the global knowledge economy, as opposed to the earlier, easier task of technological catch-up. Moreover, economic growth and innovations in the global marketplace are increasingly coming from young but fast-growing entrepreneurial firms (“scale-ups”), rather than large, incumbent corporations. While the Schumpeterian destruction of large incumbents by new disruptive innovators has been a constant in economic history, the speed at which such disruptions are occurring appears to have increased in recent years as digital transformation intensifies and the so-called fourth industrial revolution begins to take shape. As highlighted by Schwab (2016), while digital technologies have enabled revolutionary advances in internet/mobile applications and e-commerce, it is when digital technologies are applied to rapid advances in technologies that are physical (autonomous vehicles, new materials, 3D printing, advanced robotics etc.) or biological (genetic engineering, neurotechnology, bioprinting etc.) that major transformational impacts occur. This report uses the term “deep technologies” as a shorthand for these advanced physical and biological technologies underlying Industry 4.0.

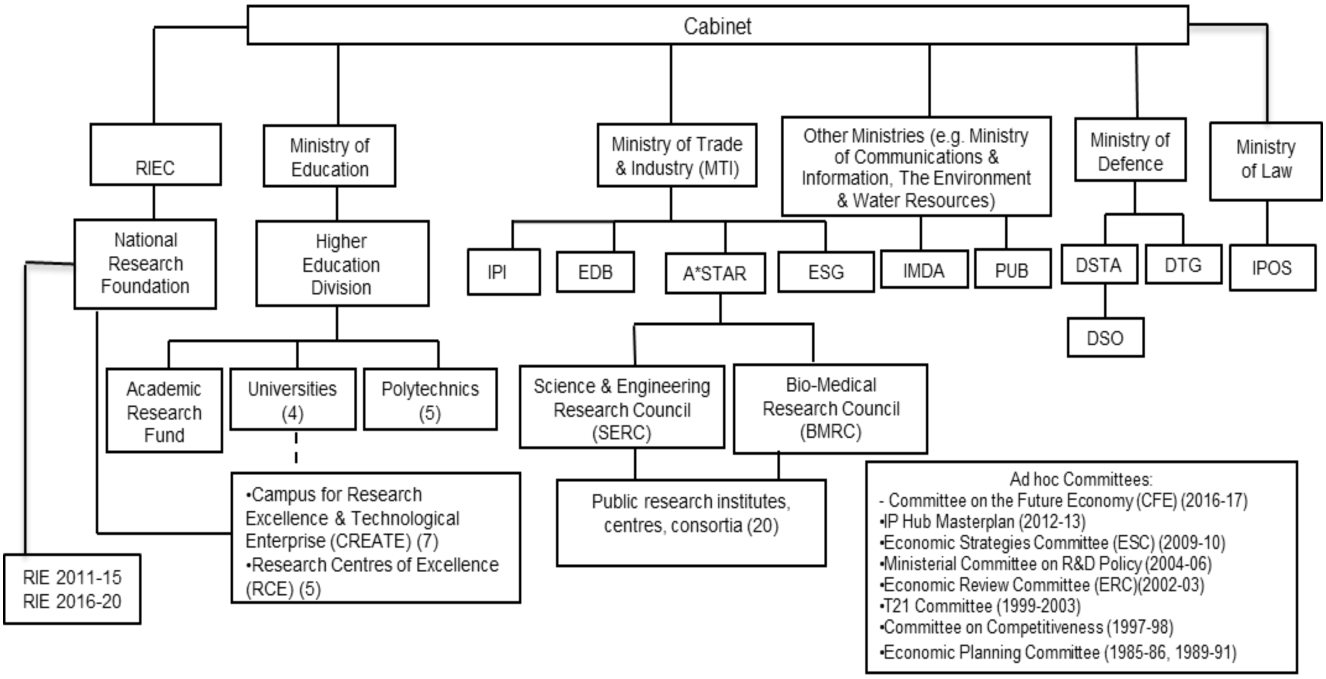
Public policymakers’ growing concern with promoting technology entrepreneurship has become a worldwide phenomenon, with many countries and regions announcing their intentions to grow their own versions of Silicon Valley (Lerner, 2009). A number of earlier works (Wong, 2001; 2003; 2006; Wong and Singh, 2008; Wong, 2019) examined the emerging shift of Singapore's economy from the late 1990s to the mid-2010s toward a more "balanced" development model that reduces its high degree of reliance on large enterprises (both local government-linked corporations and foreign MNCs) by growing the technology entrepreneurship sector. Part A of this report will use the lens of the innovation ecosystem to examine this emerging shift in greater details, as well as to update the progress of this shift up to the end of 2020. In particular, it will show that, while there has indeed been significant growth of the technology entrepreneurship sector within Singapore's innovation ecosystem, driven in part by various new *supply-side* public policies, this growth has been primarily in internet/mobile/e-commerce services, with relatively few indigenous deep technology-based "scale-ups" emerging. However, we show that, in a number of innovation clusters where the public sector can play a critical *demand-generation* role, such as urban infrastructure and health care services, Singapore has made significant progress in terms of innovation deployment, which in turn has stimulated the growth of indigenous innovative start-ups. In addition, we observe that the Covid-19 pandemic appears to have accelerated the development of these innovation clusters. The report argues that the experience of Singapore suggests the need to examine the role of the public sector in stimulating innovation through both supply-side and demand-side policies.

Part A of this report is organized as follows. In the first section, it provides a stylized institutional analysis of Singapore's public policy approach to developing its innovation ecosystem. The second section proposes a simple innovation ecosystem framework, adapted from Engel (2016), to serve as a guiding framework for organizing my analysis of Singapore's innovation ecosystem and its evolution over the years. The third section uses the proposed framework to provide some salient empirical evidence on how the innovation ecosystem of Singapore has evolved, and how public policies may have contributed. The fourth section provides a closer look at a number of innovation clusters where the public sectors have played a particularly significant role – smart cities and health care. The final section makes some concluding observations and highlight a number of relevant policy implications for Singapore.

1.1 Singapore's institutional framework for innovation and entrepreneurship policymaking and implementation

A national institutional framework for innovation and entrepreneurship policymaking tends to be complex and is often path-dependent on historical contexts and political legacies, even as it evolves over time in response to changing global and domestic environments (OECD, 2012). As such, the institutional framework of every nation tends to have its own idiosyncratic elements, and Singapore is no exception.

Figure 1 Singapore's institutional framework for innovation & entrepreneurship policy as of early 2021



EDB – Economic Development Board
A*STAR – Agency for Science, Technology & Research
SPRING – Standards, Productivity and Innovation Board
IDA – Infocomm Development Authority
MDA – Media Development Authority
DSTA – Defence Science & Technology Administration
DTG – Defence Technology Group
DSO – Defence Science Organisation
RIEC - Research, Innovation and Enterprise Council
PUB – Public Utilities Board

Lacking an official version of how the Singapore government organizes its innovation and entrepreneurship policy functions, we have created a stylized overview of the institutional framework for innovation and entrepreneurship policymaking and implementation in Singapore that has emerged since the early 2000s, or about two decades ago (see Figure 1). Policymaking related to innovation and entrepreneurship in Singapore falls within four basic groupings of state institutions:

The National Research Foundation (NRF) under the prime minister's office (PMO), which provides overall funding and broad policy guidance through five-year research, innovation and enterprise (RIE) plans, the first three being RIE2011–15, RIE2016–20 and RIE2021–25

The Ministry of Education (MOE), which oversees the education and research activities of the various institutions of higher learning (IHLs)

The Ministry of Trade and Industry (MTI), which oversees the key economic implementation agencies: the Economic Development Board (EDB, responsible for attracting inward foreign investments); Enterprise Singapore[1] (ESG, responsible for promotion of local enterprises,

[1] Enterprise SG was created on April 1, 2018, through the merger of SPRING and IE Singapore, which cover the domestic and international development of local enterprises, respectively.

particularly SMEs and start-ups); and the Agency for Science, Technology and Research (A*STAR, responsible for implementing mission-oriented public R&D)

Agencies within other ministries that have significant innovation-promotion mandates within their specific industry verticals. Figure 1 highlights the most important ones: (a) the Infocomm Media Development Authority (IMDA) under the Ministry of Communications and Information (MCI), for the ICT and digital media industries; (b) the Public Utilities Board (PUB) under the Ministry of the Environment and Water Resources (MEWR), for the water industry; (c) the Ministry of Health (MOH), for the health care industry, and (d) the Defense Science and Technology Agency (DSTA) under the Ministry of Defense, for the defense industry. We also separately highlight the Intellectual Property Office of Singapore (IPOS) under the Ministry of Law, which is not industry-specific but promotes innovation broadly through enabling legal frameworks for IP protection and transactions.

Collectively, these four groupings of state institutions have been responsible for policies and programs that have had significant direct or indirect impacts on innovation and entrepreneurship activities in Singapore. The report highlights the main roles of the key agencies identified in Figure 1, under the four key policy roles (see Table 1).

Table 1 Key innovation policy roles of public institutions in Singapore

State institutions	Creating indigenous sources of technological capability	Leveraging foreign sources of technological capabilities	Facilitating diffusion and adoption of new technologies by existing firms	Promoting the formation and growth of tech start-up firms
National Research Foundation	Fund public R&D	Fund foreign universities to establish R&D in Singapore (through the CREATE program)	Fund university-industry collaboration and entrepreneurship education activities	Co-fund venture capital funds (ESVF) and incubators (TIS)
			Co-fund corporate venture funds	Incubate and invest in tech start-ups through SGInnovate
Ministry of Education - Universities	Develop technical talents	Attract foreign students to Singapore through scholarships, etc.		Develop entrepreneurial talents
	Conduct basic R&D	Recruit foreign scientists through professorships and postdoctoral positions	Transfer R&D results to industry through licensing	Promote R&D commercialization through spin-offs
- Polytechnics and vocational schools	Conduct applied research		Assist enterprises to absorb new technologies and innovations	Develop entrepreneurial talents
			Train workforce in relevant skills to absorb new technologies	
Ministry of Trade and Industry (MTI) - Agency for Science, Technology and Research (A*STAR)	Conduct public R&D	Develop local STEM talent through PhD scholarships in prestigious overseas universities	Transfer R&D results to industry through licensing;	Promote R&D commercialization through spin-offs
			transfer R&D personnel to local SMEs	
- Economic Development Board (EDB)		Attract foreign MNC R&D and innovation activities to Singapore through tax incentives, etc.	Fund MNCs and large local enterprises to help local SMEs to upgrade (through LIUP program)	Invest in tech start-ups (through VC fund EDBI)
- Enterprise Singapore (ESG)			Promote adoption of new technologies and innovation by local SMEs through grants, subsidies, and technical services	Co-fund angel investments and incubators

			Promote industry networking	Promote tech start-ups through various grant schemes
Ministry of Law - Intellectual Property Office of Singapore (IPOS)	Provides a conducive policy and legal framework for IP creation, protection and utilization	Promote Singapore as a global IP hub, attract foreign firms to create and management IP in Singapore, make Singapore a global IP dispute resolution centre	Fund training of IP and tech transfer professionals, and IP Education for public and industry	
<u>Industry-Specific</u> **Ministry of Communications and Information (MCI)** - Infocomm Media Development Authority (IMDA)		Attract foreign MNCs and talent in ICT and media to Singapore	Promote adoption and diffusion of ICT and digital media innovation	Invest in start-ups in ICT and digital media (through VC fund Infocomm Investments Pte Ltd [IIPL]) and procure from start-ups
Ministry of Defence - Defence Science and Technology Agency (DSTA)	Fund defense-related R&D	Procure critical defense technologies from overseas	Diffuse defense technologies to local defense industry	Invest in start-ups in defense technologies (through VC fund CapVista)

Source: compiled by author.

Unlike many other countries, Singapore does not regularly create five-year economic development plans. Instead, the government convenes ad-hoc, inter-ministerial committees to formulate national economic development strategies as and when deemed necessary, often in response to significant changes in the external environment. For example, the Economic Planning Committee 1985, the Committee on Competitiveness 1997 and the Economic Strategies Committee 2009 were convened in response to the severe recession in 1985, the Asian financial crisis in 1997 and the global financial meltdown in 2008, respectively. A Future Economy Council (FEC) was formed in early 2017 to chart new strategies in response to Industry 4.0 disruptions (FEC, 2017). FEC in turn established an Emerging Stronger Taskforce (EST) in response to the Covid-19 pandemic.

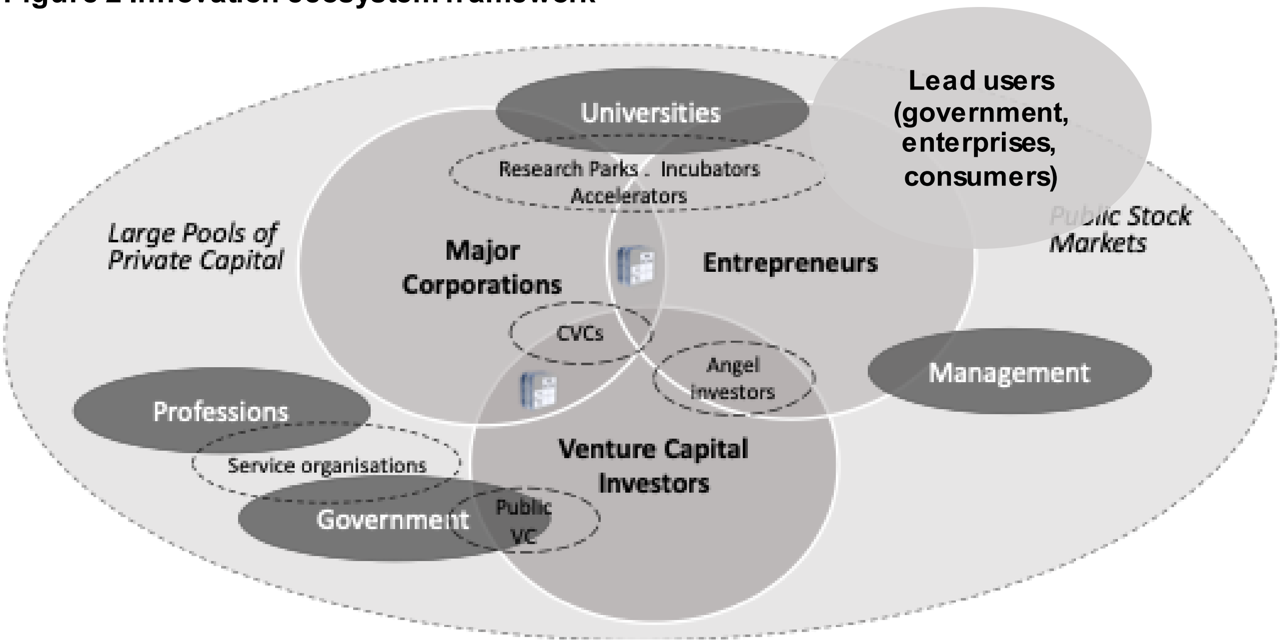
Through these strategic plans, new strategic directions related to innovation and entrepreneurship were announced, which then led to the subsequent introduction of policy and program changes. In some cases, changes are made to the institutional framework as well. For example, the 1999–2003 Technopreneurship 21 Committee for the first time identified the promotion of technology entrepreneurship as a key policy goal, which led to a slew of new programs, including the establishment of a 1-billion US dollar Technopreneurship Investment Fund (TIF) under A*STAR (then called NSTB) to invest in venture capital funds and to jump-start the venture capital industry, and the creation of the SEEDS scheme under the Economic Development Board (EDB) to match investment in start-ups by angel investors. The 2002–03 Economic Review Committee (ERC) further expanded the promotion of tech startups by making it a new function for SPRING, which also took over the SEEDS scheme from the EDB, while the 2004 Ministerial Committee on R&D Policy led to the establishment of the National Research Foundation (NRF) in 2006 (Wong and Ho, 2008). The 2017 Future Economy Council (FEC) Report led to the merger of SPRING with IE Singapore in 2018 to become Enterprise Singapore (ESG), addressing a concern that IE Singapore had in the past focused only on helping the larger, more established local enterprises to go overseas, not early-stage tech start-ups.

1.2 Innovation ecosystem framework

Drawing on the Clusters of Innovation (COI) framework proposed by Engel (2016), we propose a simple framework for identifying the key actors that play important, dynamically interacting roles in the innovation ecosystem of any economy (Figure 2). As highlighted in Figure 2, the innovation ecosystem framework emphasizes the symbiotic role of two key actors – large innovative enterprises and start-up/scale-up entrepreneurs, and one key enabling resource supplier, the venture investors that fund them. The framework also acknowledges the important contributing roles of two major institutions – government and universities – and two specialized human resources – management that have the experience to scale-up start-ups, and innovation-related professional services that reduce the transaction costs of the start-up to scale up to the exit process (IP professionals and venture investment lawyers, mergers and acquisitions (M&A) and initial public offering (IPO) investment bankers etc.). A number of subcategories of the above seven key actors are also identified (research parks, accelerators and incubators that facilitate the interactions of universities with the three key actors; corporate venture capital (CVCs) and angel investors that have emerged from the large corporations and (previously successful) entrepreneurs; and professional service organizations and venture investment programs that have significant public-sector involvement, either directly or indirectly).

The proposed innovation ecosystem framework has also incorporated an actor category called "Innovation Lead Users," comprising of public-sector agencies, enterprises and individual/household consumers who, through their willingness to be *early* adopters of relatively unproven new technologies or novel forms of services, provide the needed "beachhead" *market demand* for such nascent innovations (Moore, 2014), thereby enabling these innovations to diffuse more widely to the larger population over time across the innovation-adoption life-cycle.

Figure 2 Innovation ecosystem framework



1.3 Singapore's innovation and entrepreneurship ecosystem development

Using the above innovation ecosystem framework, the report will attempt to collate relevant empirical evidence from various sources, including my own research, to provide a picture of how Singapore's innovation and entrepreneurship ecosystem has developed over the three time periods – before 2000, early 2000–2010 and after 2010. While there are unfortunately glaring information gaps, we believe a number of clear and salient patterns can be discerned, which are highlighted below.

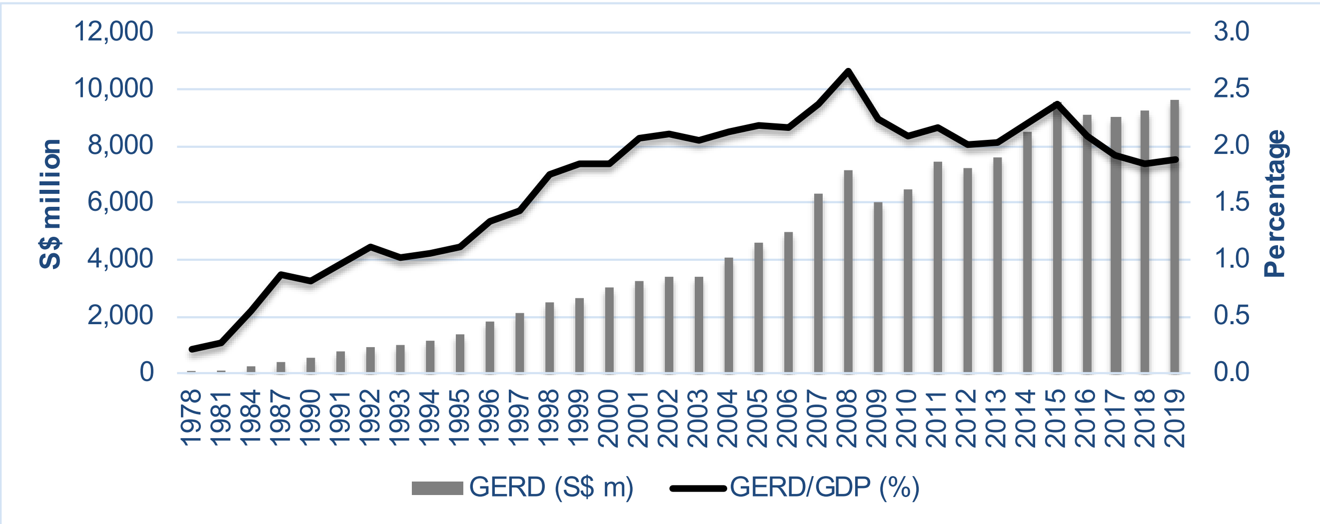
2 Overview of the R&D performers in Singapore

The size and composition of Singapore's R&D performers can be measured through a number of well-established indicators: R&D intensities, scientific publications and patenting.

2.1 Investment in R&D

After two decades of rapid growth from 1990 to 2010, gross R&D spending (GERD) in Singapore appears to have entered a period of more moderate growth over the last 10 years, with the GERD-to-GDP ratio stabilizing around 2 percent in the mid-2010s and actually showing a slight decline since (see Figure 3). While this puts Singapore comfortably within the lower half of the middle band of OECD countries, it is notably behind the Republic of Korea, Japan, Taiwan Province of China and China in Asia, and small advanced economies like Switzerland, Denmark, Finland and Israel.

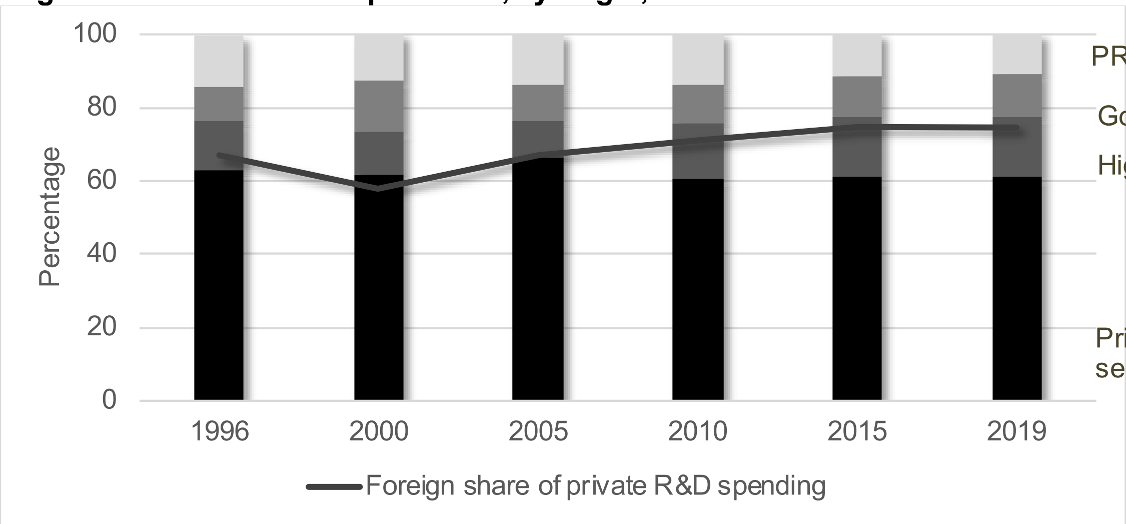
Figure 3 Growth in Singapore R&D spending, 1978–2019



Source: National Survey of R&D Expenditure and Manpow er (various years), Science Council of Singapore (prior to 1990); National Survey of R&D in Singapore (various years), National Science & Technology Board (for 1990–-2000) and Agency for Science, Technology & Research (2001 to 2018); National Survey of Research, Innovation and Enterprise in Singapore 2019, Agency for Science, Technology & Research.

The share of Singaporean R&D by private sector has also been relatively stable, at around 60 percent over the last decade (Figure 4). However, the share of local firms in this private R&D spending has actually steadily decreased from around one third in 2005 to just above one quarter since mid-2015, suggesting continuing low engagement in innovation activities by indigenous firms. In particular, according to the annual R&D survey conducted by A*STAR, the share of local firms in private R&D spending has declined the most in manufacturing, falling to less than 20 percent since the early 2010s (A*STAR, various years).

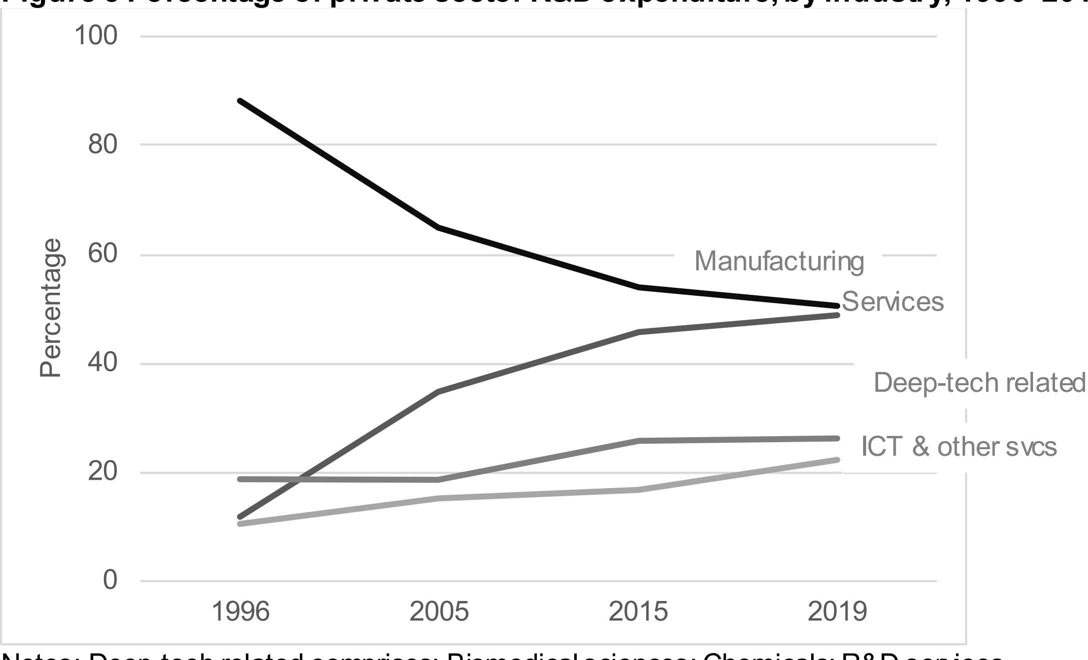
Figure 4 Share of R&D expenditure, by origin, 1996–2019



Source: National Science & Technology Board (for 1996–2000) and Agency for Science, Technology & Research (2005–2019).

The sectoral composition of private R&D has also changed rapidly over the years, with the share of manufacturing dropping steadily to less than 50 percent by 2018 (Figure 5). Over the last decade, there has been a moderate rise in the share of R&D in the deep technology-related sector (defined more narrowly to comprise only of biomedical, cleantech/energy and advanced engineering) to over one third, while that of ICT and internet/mobile-related services has increased from around 15 percent over 2005–2015 to almost one quarter by 2018.

Figure 5 Percentage of private sector R&D expenditure, by industry, 1996–2019



Notes: Deep-tech related comprises: Biomedical sciences; Chemicals; R&D services
ICT & other services comprises: ICT + logistics + wholesale/retail + others.
Source: National Science & Technology Board (for 1996-2000) and Agency for Science, Technology & Research (2005–-2019).

2.2 Scientific publications

The number of scientific publications has also continued to grow steadily over the last decade compared to earlier periods. Measured in terms of the number of publications per million population, Singapore was already ranked among the highest in the world by 2013 (NSF, 2016). This quantitative growth has continued since, and is also accompanied by a moderate increase in quality, as measured by Web of Science (WoS) citation impacts, for example, the proportion of Singapore's publications among the top 10 percent of most highly cited publications worldwide has increased from 15 percent in 2008 to 19 percent in 2018 (NSF, 2020).

Further analysis of the sources of this steady improvement in scientific publication outputs suggests that the public-sector research organizations, particularly the two universities, the National University of Singapore (NUS) and Nanyang Technological University (NTU), along with A*STAR have contributed disproportionately to the growth in both quantity and quality. Various annual global rankings of universities in the world have shown a steady rise in the ranking of NUS and NTU over the last 20 years, with NUS ranked 24th and 15th in the world (and second and first in Asia) by Times Higher Education and Quacquarelli Symonds, respectively, in 2019–2020. However, if we remove publications by the universities and public research organizations, Singapore's scientific publication outputs by private firms appear to be much less impressive.

2.3 Patenting intensities

In contrast to scientific publication output and R&D spending, Singapore's patenting outputs (as measured by patents granted by the United States Patent and Trademark Office (USPTO) to inventors based in Singapore) have increased much more sharply, from 1,320 in the period 1986–2000 to almost 5,700 in 2001–2010 and over 13,400 in 2011–2020 (see Annex Figure A). However, the growth in patenting outputs is faster among foreign enterprises than local organizations; indeed, if we remove public-sector organizations (PRIs and universities), the growth of patenting by local private-sector firms has been significantly slower than for foreign firms, confirming the substantially lower technological innovation intensities of local firms. As of the end of 2019, only four among the top 20 US patent owners in Singapore are Singaporean entities, with three being public-sector organizations (A*STAR, NUS and NTU) (Annex Table B). Only two indigenous enterprises are among the top 50, and only one (Creative Technology) owned more than 100 patents invented in Singapore. In particular, none of the large government-linked corporations (GLCs), including the three large telecommunications firms and those in advanced engineering (ST Engineering) and offshore engineering (Keppel, Sembawang), had more than 35 patents (Annex Table B).

Taken together, the above indicators strongly suggest that Singapore's R&D performers continued to be highly dominated by foreign firms and public-sector research organizations. This skewness underscores the low progress made by Singapore toward developing the R&D capability of its indigenous firms.

3 Contribution of R&D investments to Singapore's economic development

To further examine the implications of the above empirical observations, we conducted an econometric analysis of the contribution of R&D investment to Singapore's economic growth over the period 1978–2012 (Ho and Wong, 2017). Our analysis results, summarized in Table 2, show that Singapore's short-run productivity impact of R&D (as measured by the elasticity of total factor productivity (TFP) changes to R&D changes) over this period was comparable to those of smaller advanced economies among the OECD countries. However, in terms of long-run R&D productivity, Singapore lagged behind these smaller OECD countries and far behind the large G7 countries. We further tested for possible changes in R&D productivity in the 2003–2012 period versus the earlier period but found no evidence of significant structural breaks. Finally, our analysis found weaker direct productivity effect of public- versus private-sector R&D, although additional Granger causality analysis reveals that public R&D did stimulate private-sector R&D in later years.

Table 2 Estimates of R&D-TFP elasticities in Singapore vs. OECD countries

	Singapore (Ho & Wong,2017)	**Singapore (Ho et al, 2009)**	**Greece (Voutsinas & Tsamadias, 2014)**	**16 OECD countries (Guellec and van Pottelsberghe de la Potterie, 2001)**	**22 OECD countries + Israel (Coe and Helpman, 1995)**
Dependent variable	TFP (based on GDP)	TFP (based on GDP)	TFP (based on GDP)	Private sector TFP	Private sector TFP
Period of estimation	1978–2012	1978–2001	1987–2007	1980-–1998	1971–1990
Short-term elasticity with respect to R&D	0.025	0.013	Non-significant	0.024 (private R&D) 0.028 (public R&D)	NA
Long-run elasticity with respect to R&D	0.091	0.081	0.038 (total R&D) 0.075 (public R&D)	0.13 (private R&D) 0.17 (public R&D)	0.078 (non-G7) 0.234 (G7)

Source: Ho and Wong (2017)

In view of the high share of Singapore's R&D by foreign firms and public R&D institutions, the above findings suggest (1) leakage of value capture from R&D, possibly made worse by the greater propensity of foreign firms to commercialize their R&D knowledge outside Singapore, and (2) frictions in transferring public R&D knowledge to private firms, possibly made worse by the low absorptive capacity of local firms. The finding that overall R&D productivity had not improved much up to the early 2010s also suggests that there had been no significant structural changes in Singapore's innovation system, despite various public policy changes, up to the early 2010s. To the extent that these interpretations of our econometric findings are valid, they highlight the urgency of more significant policy changes to address this fundamental weakness of Singapore's innovation ecosystem – the underdevelopment of R&D capability of indigenous firms. A more updated analysis covering the more recent time period up to 2020 is also recommended.

4 Development of the technology entrepreneurship ecosystem

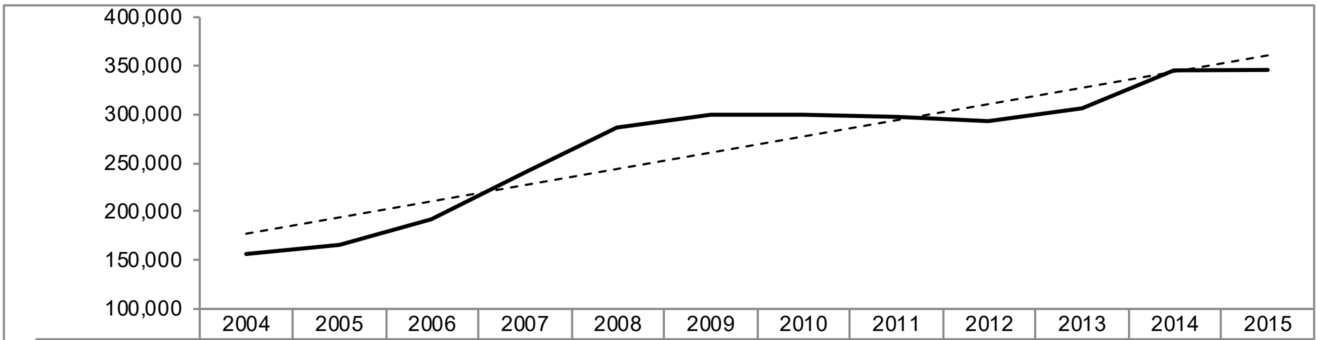
To complement the above analysis on R&D activities, the report now turns to examine the development of technology entrepreneurship, based on data from two research projects already conducted. The first (Wong *et al*., 2017) involves a compilation of unpublished census data from the Singapore Department of Statistics (DOS) on new firm formation in Singapore over the period 2004–2015, as well as primary data on 530 tech start-ups collected through a questionnaire survey in 2016. The sectoral composition of the survey respondents was found to be representative of the DOS census data. The second study (Wong and Ho, 2018) draws on an ongoing online database of start-ups called TechSG that was initiated in 2015 to identify Singapore-based tech start-up entities and their founders/investors by periodically crawling the most popular websites of business news and start-up social media (e.g., e27, TechinAsia), the homepages of VC funds, incubators and government agencies, as well as through crowdsourcing of inputs from the start-up community. Further information about these start-ups were gathered from their websites and in some cases their company registration records, to remove start-ups that have de-registered and other nonrelevant cases and to provide more fine-grained classification. Despite possible biases in coverage (e.g., start-ups that did not have their own websites were usually excluded), TechSG has been widely acknowledged as the most comprehensive publicly available information on Singapore's tech start-up ecosystem; as of early 2018, it contained information on over 2,600 start-ups and their founders, over 230 venture investors, 42 incubators and 50 other professional services firms/organizations.

We start with an overview of the aggregate growth trend of start-ups and their share of total employment in the economy (Wong *et al*., 2017). For the purpose of this analysis, start-ups are defined as young firms of five years old or younger, with at least 50 percent of capital individually owned (to remove young firms that are subsidiaries of other firms). As can be seen from Figure 6, the number of start-ups in Singapore more than doubled, from about 22,800 in 2004 to over 48,000 in 2015, while total employment likewise more than doubled from 156,500 to 345,300. Start-ups' share of total employment also increased from 7.1 percent in 2004 to 9.4 percent in 2015 (note that the temporary peak of around 10 percent over 2008–2010 was due to slower employment growth in existing firms, especially large firms, caused by the global financial crisis in 2008).

Figure 6 Growth in start-up employment, 2004–2015

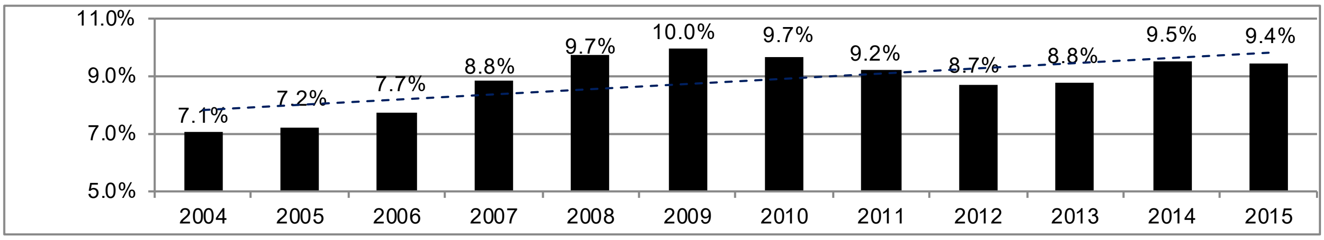
Number of start-ups
2004 = 22,819
2015 = 48,071

Growing employment by Singapore start-ups, (2004–2015)



	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Startup Jobs (#)	156,537	166,808	192,626	240,774	287,029	298,820	300,136	296,868	292,942	305,807	345,367	345,304

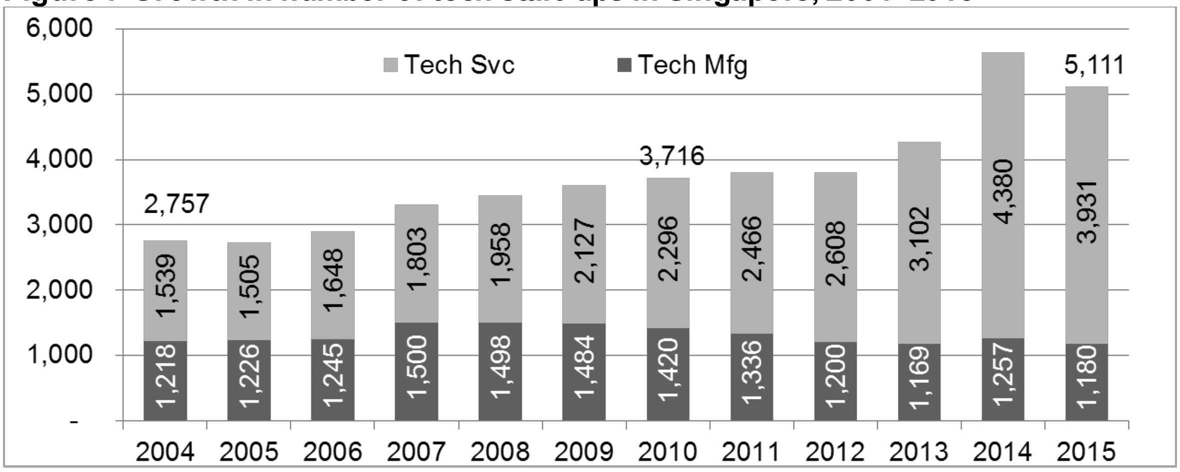
Growing contribution of start-ups to total employment in Singapore



Note: Start-ups defined as firms five years old or younger and with at least 50% individually-owned capital.
Source: DOS unpublished data compiled by author.

The above trend pertains to all start-ups, not just tech start-ups. Following other scholars, we define tech start-ups as those in industries that have above-average R&D intensities (using three-digit ISIC classification levels where available). As shown in Figure 7, the total number of tech start-ups increased at a lower rate than total start-ups, from around 2,760 in 2004 to over 5,100 in 2015. This is due to a decline of tech start-ups in the manufacturing sector since 2007, while tech start-ups in services more than doubled from around 1,540 in 2004 to over 3,900 in 2015.

Figure 7 Growth in number of tech start-ups in Singapore, 2004–2015



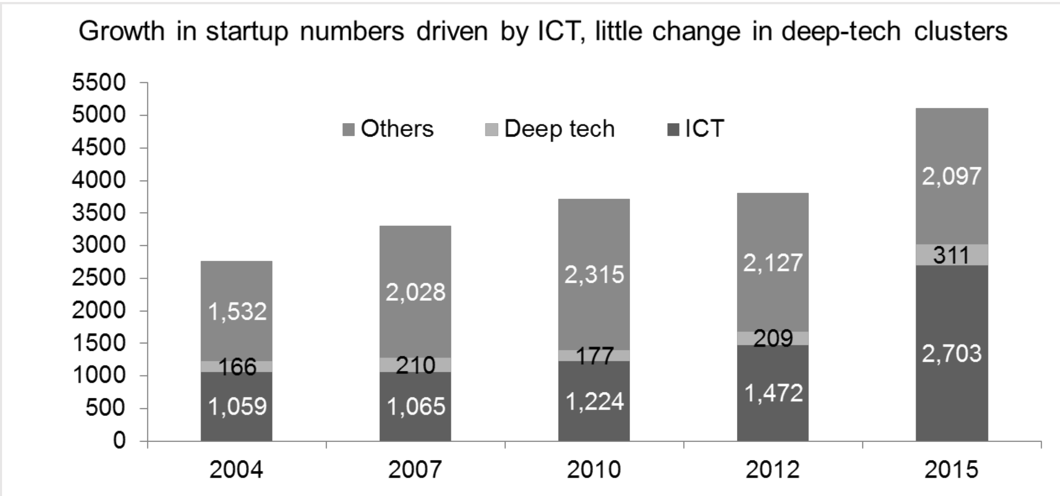
Annual growth in number of startups (%)

	Tech Mfg	Tech Svc	All Tech Startups
2004-2010	2.59%	6.89%	5.10%
2010-2015	-3.64%	11.35%	6.58%

Sources: DOS and ACRA, unpublished data compiled by author.

A more detailed breakdown of the sectoral composition of tech start-ups suggests that the biggest growth has been in ICT-related sectors, with the share of deep technology sectors (defined more narrowly as biomedical, cleantech/energy and advanced engineering) largely stagnating at around 6 percent (see Figure 8).

Figure 8 Sectoral composition of tech start-ups in Singapore (Census Data), 2004–2015

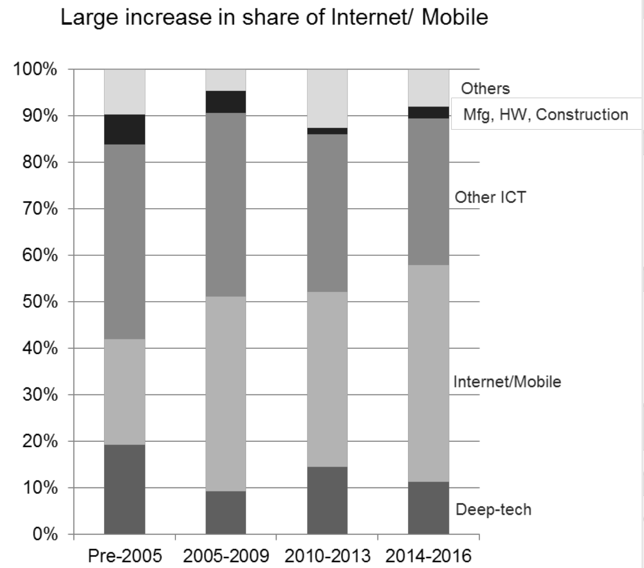


% distribution	2004	2007	2010	2012	2015
ICT	38.4%	32.2%	32.9%	38.7%	52.9%
Deep tech	6.0%	6.4%	4.8%	5.5%	6.1%
Others	55.6%	61.4%	62.3%	55.9%	41.0%
n	2,757	3,303	3,716	3,808	5,111

Sources: DOS and ACRA, unpublished data compiled by author.

The above data from DOS did not provide a meaningful breakdown of the ICT sector into more specific subsectors, especially the mobile/internet app subsector. To obtain more insights on this subsector, we utilized data from the TechSG database (Wong and Ho, 2018). Based on data on the year of founding extracted as of March 2016 covering 1,300 verified tech start-ups on TechSG, we found a similar trend of a significant increase in the share of tech start-ups in the ICT sector; in particular, we found the increasing share of ICT to have been due to the growth in internet/mobile (see Figure 9a). The shares of start-ups in deep technology and other high-tech sectors have either stagnated or declined.

Figure 9a Change in business activities of tech start-ups in Singapore



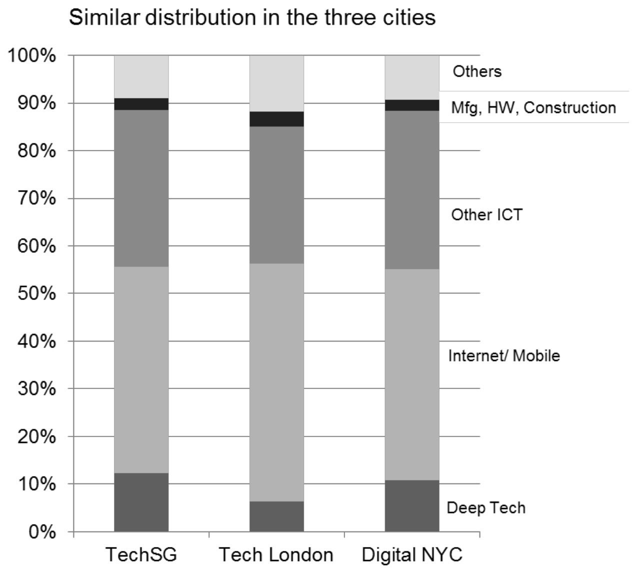
% distribution	Year of startup founding			
	Pre-2005	2005-2009	2010-2013	2014-2016
DEEP TECHNOLOGY	**19.35**	**9.30**	**14.58**	**11.19**
Biomedical	12.90	4.65	9.33	7.26
Clean Tech, Energy, Environment	6.45	3.49	4.08	2.26
Advanced Engineering	0.00	1.16	1.17	1.67
INTERNET / MOBILE	**22.58**	**41.86**	**37.61**	**46.19**
Internet, Mobile, E-Commerce	9.68	22.09	20.70	22.62
Internet Applications in Media & Lifestyle	12.90	19.77	16.91	23.57
OTHER ICT-RELATED	**41.94**	**39.53**	**33.82**	**31.19**
Software, IT Services & Solutions	16.13	25.58	11.08	11.90
ICT in Financial & Business Services	25.81	13.95	22.74	19.29
Manufacturing, Hardware & Construction	**6.45**	**4.65**	**1.46**	**2.50**
Others	**9.68**	**4.65**	**12.54**	**7.98**
TOTAL (n)	100% (31)	100% (86)	100% (343)	100% (840)

Source: Calculated from TechSG database (http://www.TechSg.io).

Data from the 2016 survey of 530 tech start-ups in Singapore (Wong *et al*., 2017) further indicate that the majority of Singaporean ICT start-ups in general and internet/mobile start-ups in particular were mostly founded by relatively young university graduates, in contrast to founders of deep technology start-ups, of whom a higher proportion had master's degrees or doctorates. In addition, founders of tech start-ups outside the ICT sector tended to be older and a higher proportion had significant prior professional/managerial work experience in industry.

Figure 9b provides further insights into the sectoral composition of tech start-ups in Singapore by comparing our TechSG data with those of London and New York, which were compiled using a similar methodology. Interestingly, the share of start-ups in ICT in Singapore was comparable with those of London and New York (76 vs. 79 vs. 73 percent), and likewise for internet/mobile only (43 vs. 50 vs. 42 percent). The share of deep tech sectors in Singapore was also comparable to that of New York City (12 vs. 10 percent), with London lower (6 percent).

Figure 9b Business activities of tech Start-ups in Singapore versus London and New York



% distribution	TechSG	Tech London	Digital NYC
DEEP TECHNOLOGY	**12.15**	**6.37**	**10.20**
Biomedical	7.77	4.17	7.45
Clean Tech, Energy, Environment	2.92	2.13	2.75
Advanced Engineering	1.46	0.17	0.001
INTERNET / MOBILE	**43.08**	**49.88**	**41.60**
Internet, Mobile, E-Commerce	21.77	24.51	21.03
Internet Applications in Media & Lifestyle	21.31	25.37	20.57
OTHER ICT-RELATED	**32.69**	**28.73**	**31.16**
Software, IT Services & Solutions	12.69	10.54	11.93
ICT in Financial & Business Services	20.00	18.19	19.22
Manufacturing, Hardware & Construction	2.46	3.25	2.28
Others	9.00	11.76	8.70
TOTAL (n)	**100% (1,300)**	**100% (1,726)**	**100% (5,264)**

Source: Calculated from TechSG database (http://www.TechSg.io).

The above comparative analysis suggests that Singapore's tech start-up pattern as of the mid-2010s reflected other global financial, business and information services hubs such as London and New York City, with a significant focus on internet/mobile services that leverage off the digital information hub role. Despite significant R&D investment in various deep technology fields, Singapore still lacked the depth and specialization of other high-tech start-up hubs, such as Boston and San Diego in life sciences, Silicon Valley in semiconductor/digital devices, big data, clean tech and energy, and Munich in advanced engineering and manufacturing. Indeed, while several internet/mobile e-commerce start-ups from Singapore have successfully scaled up regionally and achieved unicorn status (a market valuation of above 1 billion US dollars in recent years; e.g., SEA, Grab, PropertyGuru, Carro, Carousell and Ninja Van; Teng, 2021), there had so far been only a couple of deep tech scale-ups in Singapore with market capitalization exceeding 1 billion US dollars (Nanofilm in nanotechnology, listed on the Singapore Stock Exchange in March 2020, and Patsnap in IP big data/ML analytics, achieving unicorn status with its latest round of funding in 2021).

4.1 Summary assessment using the innovation ecosystem framework

Further expanding on the above analysis of the growth trend and salient characteristics of R&D performers and entrepreneurial start-ups in recent years, we have also analyzed the development trends of the key specialized resources identified in the innovation ecosystem framework (venture investors, incubators/accelerators and professional services firms) over the same periods. Table 3 summarizes the key changes in the size and composition of the key actors in Singapore's innovation and entrepreneurship ecosystem over three periods – before 2000, 2000–2009 and 2010 onwards.

Table 3 Key changes in Singapore's innovation ecosystem based on the COI Framework

Salient COI characteristics	Possible role of public policies
1985–late 1990s	
Key performers	
Mainly subsidiaries of global manufacturing MNCs doing in-house process innovation or software/IT services, a small number of MNCs doing software development and IT services	EDB played key role in attracting global MNCs to establish operations in Singapore, and in providing R&D tax incentives to encourage them to raise productivity through applied R&D The first Science Park was established by JTC in mid 1980s to facilitate the location of these MNC doing applied R&D activities and software/IT services
Some spin-outs from these MNC manufacturing, mainly in precision engineering and contract manufacturing Very few tech start-ups (Creative Tech is the rare exception)	The LIUP program contributed to developing the technological capabilities of the suppliers to these MNCs EDBI was established by EDB to provide VC and PE investment, but its investment targets are primarily global, late stage and with the view of attracting them to establish operation in Singapore later
Supporting institutions	
Local universities mainly teaching institutions with limited R&D budgets and capabilities	There were little patenting and licensing outputs from NUS and NTU during this period, and although the first Science Park was located next to NUS, there was little interactions between NUS and the tenant companies in the Science Park
ASTAR formed in 1991 but mandate was mainly to do applied R&D to support the MNCs operating in Singapore	ASTAR's patenting and licensing outputs were low during its first 10 years of operation Several R&D institutes under ASTAR and other Ministries (e.g. DSO) were co-located in the first Science Park
Specialized resources	
Venture Capital industry was nascent and focused primarily in later stages, overseas investment deals	An early venture capital fund was established by the government (EDBI), but it focused primarily on investing in growth stages ventures
Specialized professional services firms in nascent stage	
Pool of scale-up professionals very limited	
Late 1990s–early 2010s	
Key performers	
Subsidiaries of global MNCs continue to dominate in R&D spending, some emerging shifts to product innovation; growth of technology-intensive services MNCs, especially IT/software, and pharmaceutical MNCs	EDB significantly expanded its inward investment attraction focus to cover tech-intensive services MNCs in addition to manufacturing MNCs, as well as diversified the latter to cover pharmaceutical MNCs

Limited growth of local SMEs with innovation capabilities; Some of the large local firms, including GLCs, began limited R&D and innovation programs, as well as acquisition of start-ups	SPRING introduced innovation support grant schemes for SMEs; ASTAR began GET-UP program of seconding R&D personnel to local SMEs at subsidized salaries, with option to return to ASTAR
Emergence of a critical mass of tech start-ups primarily in the internet/mobile sector	SPRING and IMDA introduced tech start-up co-investments and grants
<u>Supporting institutions</u>	
Local universities, particularly NUS, significantly expanded their entrepreneurship education and incubation support program, particularly targeted at undergraduates	NUS established NUS Enterprise and NOC program in 2001; NTU established Intuitive in 2003 and a MSc program in Technopreneurship
Local universities also significantly expand their R&D capabilities and budgets, and expanded their technology licensing offices	NRF was established in 2006 and began providing funding to the local universities for innovation-related activities
ASTAR significantly expanded its R&D scope, especially in life science/biotech, and established Exploit Tech to commercialize its invention	ASTAR expanded the number of R&D institutes under its umbrella, with the majority of the new institutes in the life-science/biotech sector and located in the Biopolis
One-North, a new tech park by JTC, began construction in 2006, and opened its first phase, Biopolis, in 2011	
<u>Specialized resources</u>	
Emergence and growth of angel investor and VC industry	A US$1 billion fund-of-fund, TIF, was launched by the government in 2000 primarily to invest in overseas VC funds to attract them to establish operation in Singapore, although a number of indigenous VC funds were spawn (e.g. TDF, iGlobe); the first Angel Network (BANSEA) was established in 2002; SPRING introduced angel co-investment scheme in 2003; NRF launched the Early Stage Venture Funding Scheme (ESVF) in 2008 to jumpstart early stage VCs;
Emergence of specialized professional services firms	A number of overseas incubators and accelerators (e.g. Plug and Play, StartUp 500) and IP advisory services (e.g. Transpacific IP) established presence in Singapore; some local law firms started start-up practices
Pool of scale-up professionals remained limited	A small number of experienced scale-up professionals from overseas, especially Silicon Valley, returned or moved to Singapore to join the first wave of scale ups funded by overseas VCs
Early 2010s–-early 2020s	
<u>Key performers</u>	

Increasing establishment of regional R&D centres/innovation hubs/corporate accelerators by global tech MNCs	EDB’s inward investment attraction strategy increasingly focused on innovation-driven global MNCs (e.g. Facebook, Google, Dyson), and broadened to include Chinese (e.g. Huawei, Tencent, Tik-Tok) and regional tech companies (e.g. Gojek from Indonesia)
A small number of large local enterprises began investing more in R&D, corporate accelerators and corporate venture funds	NRF provided co-investment into several local CVCs
More local SMEs began investing in digitalization and automation, spurred by government subsidies and the adverse impacts of covid-19 (reduction of foreign workers, work from home requirements, etc)	ESG provided generous digitalization and supply chain automation grants; industry-specific technology development centres established to support innovation projects of local SMEs; ASTAR expanded the GET-UP program
Rapid expansion of tech start-up in the internet/mobile sector and emergence of a cluster of regional scale-ups and even a small number of unicorns	EDB broadened its inward attraction strategy to include experienced entrepreneurs attraction (“Entrepass” program) An emerging trend of experienced technical and managerial professionals leaving their MNC jobs to become internet/mobile/fintech start-up founders
Emergence of a critical mass of deep-tech start-ups, but only a small number reached scale-up stage	Most of the deep tech start-ups were spin-offs from the local universities and ASTAR, with a small number started by experienced technical professionals leaving their MNC jobs or foreign entrepreneurs starting up in Singapore to tap VC funding and public innovation funding
<u>Supporting institutions</u>	
Increasing shift of local university entrepreneurship education and incubation support activities towards graduate students and deep tech spin-offs	NUS launched the Lean Launchpad@Singapore in 2013 and the GRIPS program in 2019
SGInnovate was established in 2016 by the government to offer accelerator programs and co-investment of deep-tech start-ups	SGInnovate invested over S$50 mil in more than 80 tech start-ups by mid-2021
One-North became fully developed by the end of 2020, comprising Biopolis, Fusionopolis, Mediapolis, Vista and Launchpad@One North	NUS established Block 71 in One-North, which later expanded to become Launchpad@One North; a new Launchpad@Jurong is being developed next to NTU
<u>Specialized resources</u>	
More experienced entrepreneurs and investors are attracted to operate VC funds and family offices in Singapore	EDB has broadened its inward attraction programs to attract family offices by high net worth individuals, experienced scale-up professionals
VC funds began to look into investment in deep tech start-ups through co-funding support from the government	SGInnovate introduced the Startup SG Equity scheme in 2017 to co-fund 22 VC funds over the next 3 years to invest in deep-tech start-ups; Xora Capital was established in 2020 with funding from Temasek and NRF

A pool of experienced professionals from the first wave of scale-ups has emerged, and some of them began to join the second wave of scale-ups A pool of experienced deep tech start-up mentors has emerged	to invest in Seed and Series A stage deep tech start-ups that have global growth potential First wave mobile/internet scale-ups spawning scale-up professionals to staff second wave scale-ups include Grab, Zopim/Zendesk, Lazada, and PropertyGuru Lean Launchpad@Singapore helped build a national network of mentors, many were senior executives with global MNC experience; Some entrepreneurs who exited in the first wave of scale-ups (e.g. Zopim/Zendesk) have become angel investors and mentors to the second wave of start-ups

4.2 The role of public policy in Singapore's innovation ecosystem development: Supply side

Corresponding to each major innovation actor/specialized resource development trend identified in the first column of Table 3, we have also provided in column two salient information on the possible public policy interventions/programs that may have been an important contributing factor. For example, the significant growth of venture capital funding in the second development phase (2000–2009) was driven largely by the launching of a number of government co-funding schemes (e.g., ESG's Business Angel Co-Investment Scheme and NRF's ESVF). The development of Launchpad@one-north and Launchpad@Jurong have also significantly expanded the supply of low-cost space for start-ups, while the introduction of the SkillFuture program has significantly increased public funding for adult learning and skills re-training to cope with rapid technological change (Yusuf, 2020).

In the absence of detailed research to assess the actual impacts of many of the policy interventions/programs listed in Table 3, it is not possible to ascertain the effectiveness of many of these specific government interventions. A detailed study on one such program, A*STAR's GET-UP program (Ho *et al*., 2016) has found the program to have significant positive impact. However, the effectiveness of some programs (e.g., NRF's TIS program, intended to be modeled after Israel's technology incubator program) have been questioned (Wong, 2019), and concerns have been raised that generous public funding has resulted in too many internet/mobile start-ups being funded (Wong *et al*., 2017). Nevertheless, there is little doubt that government agencies in Singapore have played a very significant role in driving most of the Clusters of Innovation (COI) development trends observed in Table 3. As highlighted by a recent World Bank review of Singapore's start-up ecosystem, the significant role of the public sector is among its most prominent characteristics (World Bank, 2021). It is also worth noting that the launching of the IP Hub Masterplan in 2013 and various amendments to the country's IP legislation (e.g., Registered Designs Act and Patent Act amendments in 2017) have significantly improved Singapore's IP rights protection regimes, as reflected in the top ranking that Singapore now receives from various global IP protection ranking studies (e.g., Singapore is ranked second and third in the world, respectively, for IP rights protection by the World Economic Forum's *Global Competitiveness Report 2019* and the *International Property Rights Index 2020*) (Intellectual Property Office of Singapore, 2022).

4.3 The role of public policy in Singapore's innovation ecosystem development: Demand side

While the above analysis using the innovation ecosystem framework appears to have captured the salient characteristics of Singapore's innovation and entrepreneurship ecosystem at different development stages by looking at the performers and the enabling institutions, resources and services, that is, the *supply side* of the ecosystem, it is incomplete as it has not yet examined the roles played by actors on the *demand side*, how these actors and their roles have changed over time, and the potential role of government in influencing those changes.

As prior research literature on innovation clusters has highlighted (see, e.g., Karlsson, 2010), central to all analysis of innovation and entrepreneurship ecosystems is the role of *users* and *customers* who adopt and pay for new innovative products and services that the innovation ecosystem actors supply. The changing behavior of these demand-side actors – the changing mix of enterprises, consumers and public-sector organizations that constitute the markets for innovation – is arguably important in influencing the level and kind of innovations coming out of any innovation and entrepreneurship ecosystem over time. Globalization of markets notwithstanding, the characteristics and behavior of local and regional market users toward new, unproven products and services often have a significant impact on any local clusters of innovation, especially in their early development stage. In particular, the innovation literature has highlighted the important role of *lead users* in catalyzing technological innovation for enterprises (von Hippel, 1986). Likewise, sophisticated, tech-savvy end-consumers have also been recognized as important in driving demand for consumer-oriented technological innovation in China (Dychtwald, 2019).

By explicitly incorporating these demand-side actors and how they vary across locations and change over time, our proposed innovation ecosystem framework highlights the need for systematic data collection to provide empirical evidence on the demand-side actors, especially the *innovation lead-user* actors. Unfortunately, there is no universally agreed construct for measuring the size and composition of innovation lead-users among public-sector agencies, or the extent to which a consumer population of a country is tech-savvy. There is a Business Innovation Survey instrument for measuring the extent of innovation among businesses among OECD countries (OECD, 2018), but Singapore has unfortunately not implemented such a survey.

4.4 The innovation demand-stimulating role of the Singapore government

Due to the lack of systematic data on the role of lead-users in spurring innovation in Singapore, the report will focus instead on the role of government as an innovation lead-user in Singapore. While most of the government's facilitating roles that have been identified in Table 3 are on the supply side, we can discern significant demand-side public policy roles as well, especially in the wake of the global Covid-19 pandemic. In particular, the following key public policy roles in influencing market demand for innovation can be identified:

- the public sector itself as a lead user/customer
- public subsidies for usage/adoption by private market users (enterprises or consumers)
- public provision of infrastructure support for the deployment of the innovation
- government testing/certification to increase public trust in the safety and efficacy of new, unproven innovation
- public education and marketing communication to promote awareness, acceptance and adoption of the innovation.

A great example to illustrate these demand-side government roles is that of Covid-19 vaccination. While the large pharmaceutical companies like Pfizer and AstraZeneca and biotech therapeutics companies like Moderna are the key actors on the supply side for the Covid-19 mRNA vaccine innovation, the US government – and governments of many other nations – played a critical market demand generation role by:

- underwriting the purchase of these vaccines (even while they were still under development and in early trials) on behalf of their citizens, and distributing them for free
- establishing (and paying for) the scientific infrastructure to test and certify the safety and efficacy of the vaccines
- establishing (and paying for) the public health outreach infrastructure to distribute, train and administer the vaccination injections
- carrying out the massive public education and marketing communication campaign to convince the public to take the vaccination.

The Singapore government has certainly played a proactive intervention role in the deployment of Covid-19 vaccinations. Besides signing early procurement contracts and options for three major vaccines (Pfizer, Moderna, Sinopharm and Sinovac) while all three were still under development, the government had established a well-administered vaccination program and public education/outreach campaign to achieve a high vaccination rate by international benchmarks as of the end of December 2021 (87 percent of the population were fully vaccinated, 45 percent had received booster shots) (Ministry of Health Singapore, 2022).

While the scale and urgency of the public intervention in the market for Covid-19 vaccination is extraordinary, and entirely justified due to the enormous public interest at stake and the inability of purely private-market mechanisms to achieve fast and near universal adoption, the same considerations may also be applicable in varying degrees to other innovations that have some elements of public interest and private-market failures justifying government interventions.

In the context of Singapore, two clusters of innovations that appear to have emerged with the strong support of government on the demand side are worth examining in greater depth: public health care and "smart urban infrastructures."

4.5 Public health care

Like other advanced economies, Singapore has invested heavily in public funding of R&D in life sciences and biomedical technology (Wong, 2007; Pearson & Partners, 2019). Here, however, we want to highlight some of the demand-side policy interventions that have made tangible impacts in terms of innovation adoption in Singapore's public health care system.

<u>Contact-tracing</u>

To track the movement of prisoners under the home detention scheme, Singapore's prison authority had since the early 2010s deployed an electronic tracking device developed by a local wireless technology start-up called iWow. When Covid-19 struck, iWow was able to quickly innovate a tracking device for home quarantine, and subsequently a contact-tracing device ("TraceTogether Token") for large-scale deployment among Singapore's resident population. The widespread adoption of contact-tracing technology has enabled Singapore to react rapidly to contain the spread of Covid-19.

Rapid Covid-19 diagnostic testing

Since the 2003 SARS outbreak, A*STAR had established a Diagnostic Development Hub (DxD) to coordinate national research programs to develop a rapid SARS test kit as well as diagnostic technologies for various diseases. When Covid-19 cases emerged at the end of 2019, a DxD research team was able to work with a local hospital (TTSH) to quickly adapt the technology to detect Covid-19. With certification from the National Public Health Laboratory at the National Centre for Infectious Diseases (NCID), the test kit was approved by Singapore's Health Sciences Authority (HSA) in February 2020 for rapid deployment in 13 hospitals and labs in Singapore. After validated use in Singapore, the test kit has since been deployed to more than 20 countries globally, including New Zealand and the US (A*STAR, 2021).

More recently, in December 2020, HSA approved a new diagnostic test kit jointly developed by DxD and the Defense Science Organization (DSO) that shortened testing time from more than two hours to one hour, by using saliva instead of conventional PCR testing using a nasal swab (A*STAR, 2021). In May, 2021, HSA also gave provisional approval to a breath-testing technology developed by a spin-off from NUS, Breathonix, that can be administered on-site and provide results in 30 minutes (NUS News, 2021). The government is expected to scale the deployment of either of these at land immigration checkpoints as well as at airports and seaports once their use in selected hospitals and labs is validated.

Preventive care

Only about 3 percent of the total health expenditure among OECD countries is spent on preventive care. In Singapore, about 5 percent of the Ministry of Health's non–Covid-19-related budget in recent years has been on preventive care. These preventive health care efforts include public education campaigns, healthy lifestyle activities in schools, workplaces and community settings, engaging industry to spur reformulation of staple food products, subsidies for health screening and recommended vaccinations, regulations to protect citizen health and subsidized digital health technology adoption (Ministry of Health Singapore, 2021).

As an example of public policy to encourage the adoption of digital health technology, the Health Promotion Board (HPB) provides all Singaporean citizens and permanent residents aged 17 years and above a free fitness tracker if they sign up for a regular "National Steps Challenge" that offers reward points for shopping vouchers on achieving Total Physical Activity (TPA) targets, defined as at least 150 minutes of moderate-intensity or equivalent activities per week. This "nudging policy" has contributed to an increase in TPA among adult Singaporeans (aged 18 to 74 years) from 73.1 percent in 2013 to 80.1 percent in 2019 (Health Promotion Board, 2021).

The significant investment by the government in adopting health care innovations has contributed to making Singapore's public health care system a key innovation cluster in Asia. In 2020, the Bloomberg Health-Efficiency Index, which tracks life expectancy and medical spending, ranked Singapore second in the world for efficiency of its health care system (Miller & Lu, 2020). As of 2019, Singaporeans have the world's longest life expectancy at birth, at 84.8 years. Females can expect to live an average of 87.6 years, with 75.8 years in good health, and men have a life expectancy of 81.9 years, with 72.5 years in good health.

4.6 Smart urban infrastructures

The concept of "smart cities" has been popularized in recent years, but its definition tends to be rather broad and typically encompasses both technological dimensions as well as socioeconomic and cultural ones. For example, the Smart City Index project of IMD Business School broadly divided the various dimensions into two main pillars – a structures pillar (referring to the existing infrastructure of the cities) and a technology pillar (describing the technological provisions and services available to the inhabitants), with each pillar covering five key areas: health and safety, mobility, activities, opportunities and governance (IMD, 2020).

In the context of Singapore, we identify several key components of its urban infrastructure – urban mobility, built environment energy management, and urban water and sewerage management – that have experienced significant improvement through the adoption of technological innovations.

<u>Smart mobility</u>

Being a small city-state, since the early 1980s the Singapore government has paid significant policy attention to achieving global transport connectivity, on the one hand, and smooth intra-city urban traffic flow, on the other. To maintain its status as a global air and sea transport hub, Singapore has also built among the most efficient airport and seaport in the world, consistently ranking first in the world in the last two decades.

To achieve efficient intra-city transport, Singapore was among the first countries in the world to deploy electronic area road-pricing technology to reduce vehicular traffic congestion in peak hours. Singapore was also among the first in the world to implement a policy of high vehicular ownership tax (“certificate of entitlement”) to complement its high investment in public transport (Land Transport Authority, 2021).

With the growth of ride-hailing platform innovation around the world in the early 2010s, Singapore was able to attract Grab, a start-up originating from Malaysia, to establish its headquarters in Singapore quite early on, followed by the Indonesian firm Gojek several years later. Grab’s rapid growth to become the leading player in Southeast Asia (including its acquisition of Uber’s operations in the region) was enabled by venture capital funding from VCs based in Singapore, including Vertex Ventures, owned by Temasek, the sovereign fund of the Singapore government.

Singapore has also been among the earliest cities in test-bedding commercial deployment of driverless vehicles. Singapore’s first trial of self-driving buses was in 2015, while a trial of driverless road sweepers was launched in early 2021. Both were developed by a consortium of local university and local engineering firms. KPMG’s 2020 Autonomous Vehicles Readiness Index ranked Singapore first among 30 countries covered, up from second in 2019 (KPMG, 2020).

Singapore’s seaport and airport have been consistently ranked among the best in the world over the last two decades. Besides investing heavily in innovation to enhance their operational effectiveness and global connectivity, both have also been lead users of innovations that improve their multi-modal integration with on-land transport. For example, the Port of Singapore Authority (PSA) has innovated a highly automated flow-through gate process that enables more than 10 container truck flows per minute between the port terminal and land. Through its corporate accelerator Unboxed and its Container Port 4.0 (CP4.0) program for its new port at Tuas, the PSA has provided funding and test-bedding of not only sea-side and within-port innovations, but also innovations in third-party logistics partners that improve port–land interface (Port of Singapore Authority, 2021).

While some of the large local enterprises (e.g., ST Engineering and YCH Logistics) have benefited from these public-sector lead users, several innovative local tech scale-ups have also been spawned in recent years, with the Singapore public sector as their first validating customers before expansion to overseas markets. These include Swat Mobility (employee transport optimization software, validated in trials with the Land Transport Authority in Singapore before expanding deployment to Japan, Australia and the Philippines), Versafleet (transport management software targeting the "last mile" of urban delivery, expanded to four countries in Southeast Asia) and Haulio (a platform connecting hauliers and shippers to improve container movement on land, which gained traction in Singapore with the support of PSA before expanding to Thailand).

An Overall Urban Mobility ranking of 24 global cities by McKinsey in 2018 (covering availability, affordability, efficiency, convenience and sustainability) ranked Singapore first, ahead of Paris and Hong Kong (McKinsey and Co., 2018).

Smart built environment energy management

Technological innovations, particularly the use of digitalization, data/AI and the "internet of things" (IoT) to improve energy management and environmental sustainability, have figured centrally in all policy discussion about smart cities. In the case of Singapore, the public sector played a major role in deploying such innovations, coordinated through an inter-ministerial Smart Nation and Digital Government Office (SNDGO).

A key initiative of the SNDGO is the rollout of a Smart Nation Sensor Platform (SNSP), a nationwide wireless IoT network to improve municipal services, city-level operations, planning and security. As part of the network rollout, trials with smart wireless electricity, water and gas meters were conducted from 2018, with large-scale deployment commencing in 2022. As part of the SNSP project, the first of a series of public tenders was awarded in 2018 to turn the 100,000 lampposts on Singapore streets into "smart" lampposts. Besides replacing the existing lighting with energy-saving LEDs, the Lamppost as a Platform (LaaP) project will outfit all lampposts with digital cameras and other wireless sensors and connect them into a wireless IoT network with a remote control and monitoring system that can sense external weather conditions (temperature, humidity, environmental pollutants etc.) and foot traffic, enabling the street lights to be dimmed or brightened automatically, as well as faster incidence response for public safety. Navigational beacons are also being added onto the lampposts to guide autonomous vehicles as they get rolled out onto Singapore's streets (Smart Nation and Digital Government Group, 2021).

Major public-sector organizations were also lead users in deploying built environment energy management innovations. The Housing and Development Board (HDB), the government agency responsible for developing affordable public housing and community facilities in Singapore, has built more than 1 million flat units in 26 townships across the island, providing homes to over 80 percent of Singapore's resident population. Through the Green Towns Program, the HDB has been a major demand driver for the adoption of various energy management/sustainability innovations in Singapore, including solar panel installations (50 percent of all HDB blocks were already covered in 2020), conversion of the top decks of multistory carparks into urban farms and community gardens, pneumatic waste conveyance systems and "cool" paints that reflect more sunlight. In 2020, the HDB awarded tender to a local start-up (Anacle Systems) for the development of Smart Estate Management Systems ("SEMS") to manage its complex and diverse portfolio of properties, to digitize all workflows onto a singular platform as well as to create applications and tools to enhance service offerings to the public. Incorporating cutting-edge technologies such as 3D digital twinning and machine learning, SEMS seeks to innovate energy management and to redefine the shopping experience in all HDB commercial complexes and precinct shops, and is the largest and most technologically advanced project of its kind in Southeast Asia (Housing and Development Board, 2021).

The Energy Market Authority (EMA) operates the critical delivery infrastructure used in the supply of electricity, and develops and regulates Singapore's electricity and gas industries as well as district cooling services. Initiatives by the EMA that have spurred innovation adoption include the launching of an Open Electricity Market program in 2018 to fully liberalize the electricity retail distribution markets for all households and business premises, a national program in 2019 to replace all household electricity meters with advanced meters that can be read via mobile apps, and numerous research/innovation grants to rest/pilot new energy technologies, including Singapore's first floating Energy Storage System (ESS) in 2020 (Energy Market Authority, 2021).

Public-sector innovation deployment projects such as the above have contributed to the growth of several local technology scale-ups. A good example is Anacle Systems, which has leveraged public-sector customers such as HDB, JTC and Changi Airport to dominate private commercial property management in Singapore as well, beating out global competitors like IBM and SAP. For example, the Jewel Complex in Singapore's Changi Airport has implemented the advanced IoT Solutions, Enterprise Asset Management and Energy Management System developed by Anacle Systems. The company emerged as the largest real estate management software provider in Southeast Asia and went into an IPO on the Hong Kong Growth Enterprise Market (GEM) in 2017. The company also developed the world's smartest power meter, leapfrogging ahead of established global leaders like Schneider and GE, with Singapore's public-sector agencies among its first customers (Anacle Systems, 2021). Crucially, during the pandemic period, when the private commercial property sector had substantially cut back its investment in new technologies, demands created by these public-sector agencies were critical in sustaining the growth of Anacle Systems and other innovative start-ups in the built environment energy management industry.

Urban water and sewage treatment

As a small island state with no natural water resources beyond rainfall, Singapore has always regarded water as a vital strategic resource ever since it became politically independent in 1965. Initially relying wholly on two water supply agreements with Malaysia's Johore State (the first signed in 1961, which expired in 2011, and the second signed in 1962, which will expire in 2061), Singapore has invested heavily in research and technology to treat and recycle water so as to grow and diversify its sources of water as its consumption requirements have grown in tandem with rapid urbanization and industrialization.

Spearheaded by the Public Utilities Board (PUB), the national water agency, an integrated water and sewage management strategy was implemented, with close coordination with the National Environment Agency (NEA). Besides expanding the number of reservoirs and innovating the efficiency of collecting rainwater from local catchments, the PUB has invested heavily in water treatment technologies, from advanced membrane technologies to ultraviolet disinfection and deep tunnel sewage systems, to purify and recycle sewage water. By 2020, 40 percent of Singapore's water needs were supplied through this NEWater approach, and this is expected to increase to 55 percent by 2060. Singapore has also built four desalination plants, with a fifth by the end of 2022, each time deploying the latest available innovations in desalination technologies. The PUB also invested heavily into digital technologies, AI/big data and IoT to improve water management (Public Utilities Board, 2021).

Generous public funding for R&D and innovation test-bedding were provided by the PUB and the National Research Foundation (NRF) to promote both local R&D and pilot-scale and demo-plant studies, as well as R&D collaborations with leading global research institutes. In 2013, Lux Research ranked two universities in Singapore, NUS and NTU, as the top two water research institutes in the world in the field of membranes, desalination and reuse. In addition, to ensure that the PUB is able to tap the best technological innovations in water technology globally, the Economic Development Board (EDB) has made the attraction of global water technology corporations to establish R&D operations in Singapore one of its priorities.

By the early 2020s, Singapore had emerged as one of the leading global "hydrohubs," home to a vibrant and thriving ecosystem of 180 water companies with more than 20 water research centers spanning the entire water value chain. While foreign firms remain dominant in this innovation cluster, the PUB as an innovation lead user has certainly played an important anchoring role for the cluster. Moreover, leveraging from the capability in membrane technology initially developed for water treatment, Singapore's universities and membrane tech companies are expanding into other areas of membrane separation applications such as gas separation and purification, purification of pharmaceutical ingredients and controlled drug delivery. With funding support from the NRF, EDB and Enterprise Singapore (ESG), a Singapore Membrane Consortium was formed in 2021 to diversify this innovative cluster beyond water treatment (National Research Foundation, 2021).

4.7 Innovation demand stimulation: Summary observations

As the examples above illustrate, even though Singapore is not the originator/creator of many of the technological inventions being adopted or deployed, Singapore has often been among the first to test-bed and subsequently fully deploy these technological inventions in the public sector, that is, the Singapore government has been a *lead user* in testing, validating and adapting these new technologies, often enabling them to become viable commercial innovations that can be more broadly diffused to private-sector users. Thus, although Singapore ranked only 28th among the top 99 city-regions of the world in 2020 terms of
Science and Technology (S&T) innovation outputs as measured by patents (supply-side measures) according to the Global Innovation Index (WIPO, 2020), Singapore's ranking is substantially higher when innovation adoption measures (on the demand side) are taken into account. The Smart City Index by IMD Business School also ranked Singapore first out of 109 cities in the world for 2019 and 2020, in large part because of its high score in innovation adoption under the Technology Pillar (IMD, 2020).

In terms of the innovation ecosystem framework, while Singapore may not yet have created many successful actors on the supply side of innovations in these two innovation clusters, they have nonetheless become highly vibrant innovative clusters due to the advanced stage of innovation adoption, and the sophistication in usage among the lead-user organizations, which in turn arguably makes these organizations (seaport, airport, public housing, public health care systems) highly efficient and globally competitive. As such, Singapore's innovation ecosystem development experience suggests the need to examine more systematically the actor category called "innovation lead users," as indicated in Figure 3. While lead-user government organizations are the most important subset in the case of Singapore, in other nations or regions, the dominant lead users could be private firms (e.g., the German "Mittelstand" have been characterized as lead users of manufacturing innovations), or tech-savvy consumers (e.g., China's young consumers have been recognized as sophisticated lead users of mobile social media (Tik-Tok), mobile fintech (WeChat) and mobile e-commerce (live-streaming)).

5 Overall concluding observations

While the COI Framework has been developed primarily based on the experience of advanced market economies and regions, especially Silicon Valley in the US, it can be usefully applied to latecomer economies and regions seeking to catch up rapidly, provided we contextualize the framework to the key drivers for market demand of these economies/regions, which may differ from those of advanced economies, especially in terms of the role of the public sector. Based on the above analysis using such an augmented COI Framework, the following conclusions can be made about Singapore's innovation and entrepreneurship ecosystem development:

1. despite significant quantitative growth, a fundamental weakness remains in Singapore's innovation ecosystem: the underdevelopment of indigenous firms' innovation capability. This underdevelopment is particularly manifest among the local SME sector, although some of the large government-linked corporations (GLCs) have also been slow to invest in innovation capability development

2. while tech start-up activities have increased substantially over the last decade, these are still predominantly in the internet/mobile/IT services sector. A critical mass of deep technology start-ups appears to be finally emerging in the early 2020s, but few have as yet become "scaled-ups" with potential to be globally leading high-tech firms

3. public policy changes to support technology entrepreneurship until the mid-2010s have largely focused on enabling start-ups in the digital innovation space, particularly internet/mobile/IT services, where start-up capital requirements and gestation time for product development are relatively low. Efforts to nurture deep tech start-ups have increased significantly since the mid-2010s, particularly those seeking to commercialize R&D outputs from public research institutes and universities. Going forward, a greater policy focus to address the hurdles in public research–industry knowledge transfer and more technology-cluster-specific policies are needed. In addition, a deliberate strategy is needed to push the various quasi–state-owned enterprises or GLCs to invest more in innovation, for example, by reducing their traditional reliance on the domestic market and forcing them to compete more in the global market. Greater policy attention is also needed to address the "scale-up" challenges of tech start-ups, including challenges to penetrate the emerging markets of ASEAN

4. the public sector has played an important innovation and entrepreneurship ecosystem development role not only on the supply side, but on the demand side as well for certain key innovation clusters where the public-sector lead-user role can be catalytic, or where it is actually necessary and critical due to private market failure and social network externalities.

5.1 Implications for other newly industrializing economies

My findings on Singapore's experience in developing its innovation and entrepreneurship ecosystem hold a number of implications for other newly industrialized economies. First, policies to promote innovation system development need to be better integrated with policies to promote the growth of technology entrepreneurship. In the case of Singapore, the two sets of policies initially appear to be poorly integrated; much of the investment in public R&D has not been translated into technology commercialization, because the absorptive capacities of the existing local enterprises have not been sufficiently developed; at the same time, the many new start-ups being supported by the technology entrepreneurship promotion policies are mainly in the internet/mobile sector, which has not drawn much on the public R&D investment.

Second, as late-industrializing Asian economies intensify their efforts to catch up with advanced economies through the development of more indigenous firms with capabilities in the advanced technology sector, Singapore's mixed experience in this regard suggests the need for policymakers to take a holistic approach toward nurturing indigenous capability-building. As highlighted earlier, commercializing advanced technologies can be achieved through new start-ups or existing enterprises, so public policy needs to be framed broadly to encompass the facilitation of both pathways. Singapore's experience suggests that policymakers in recent years have paid much attention to the entrepreneurial start-up pathway, but perhaps not enough to increasing the innovative capability of existing firms, especially the large incumbent local enterprises including the GLCs. In contrast, economies like the republic of Korea may have overemphasized the second pathway to the detriment of the first.

Third, for latecomer economies with small domestic markets and limited supplies of indigenous talent, Singapore's experience in innovation and entrepreneurship ecosystem development highlights the critical importance of building strong international connectivity to attract talents as well as to access markets and venture capital. Policy-wise, Singapore has done relatively well in attracting both overseas R&D and entrepreneurial talents (and to a certain degree, overseas venture capital funding) to Singapore, although it has not done as well in terms of helping indigenous start-ups to scale up internationally.

Fourth, Singapore's Innovation and Entrepreneurship (I&E) ecosystem development experience over the last decade suggests that universities can play a potentially important role in fostering technology entrepreneurship. While the improvement of venture funding facilitated by public grants and co-funding has clearly contributed, the proactive role of local universities in providing start-up incubation support appears to have been important as well. It is also likely that the significant increase in emphasis on entrepreneurship education over the last 20 years by local universities, particularly NUS, may have also increased the supply of young university graduates predisposed to pursue start-ups versus working in large companies and the public sector (Wong *et al*., 2019).

Last, but not least, Singapore's relatively good performance in developing a number of vibrant innovation clusters with significant public-good characteristics, like health care and smart urban infrastructure, highlights the importance of integrating demand-side policies with supply-side policies. As good public governance and high public trust appear to be important, if not a prerequisite foundation, for both supply-side and demand-side public policy in sectors with significant public-good characteristics, Singapore's experience suggests the need to integrate analysis of public governance and public trust in any discourse on such innovation cluster development (Yusuf, 2020).

Part B: Mapping the changing pattern of innovation among different innovation actor groups in Singapore

To gain more insights into how Singapore's innovation ecosystem has evolved over the last 20 years, we apply patent data analysis to map out how the different groups of innovation actors have contributed to the overall growth in innovation over the years, and how the pattern of knowledge interactions among these different innovation actors has changed over time.

We acknowledge at the outset that patenting outputs measure only part of the overall innovation activities of any economy, and it is widely recognized that different industrial sectors have different patenting propensities (e.g., chemical process industries often protect their process innovation in the form of trade secrets rather than patents, and a lot of software innovations are protected using copyrights instead of patents). In addition, our use of patents granted by the United States Patent and Trademark Office (USPTO) may miss out patenting outputs not filed in the US but granted in other jurisdictions. As such, patenting data analysis gives only a partial and possibly biased picture of the overall pattern of innovation activities in an economy. Consequently, the findings of our analysis in this part of the report need to be interpreted with some caution.

1 Categorization of innovation actor groups

For the purpose of our analysis, we define an innovation actor in Singapore as any assignee of a patent granted by the USPTO that has at least one inventor resident in Singapore. We then categorize the different innovation actors (assignees) into the following innovation actor groups (see Table 4 for more detailed definitions):

- local enterprises
  - large local enterprises (LLEs)
  - small and medium-sized enterprises (SMEs), including young tech start-ups

- foreign enterprises
  - foreign enterprises located overseas
  - local subsidiaries of foreign enterprises, that is, the assignees are Singapore-registered entities, but are known to be foreign-majority-owned/controlled
- local institutions of higher learning and local public institutes (IHLs/PRIs)
- foreign institutions of higher learning and other public organizations
  - located overseas
  - with local subsidiaries in Singapore
- local individuals
- foreign individuals.

Table 4 Definitions of variables derived from USPTO patent data

Singapore-invented patents are defined as USTPO-granted patents where at least one inventor is a Singapore resident. Patent counts are by the year they were granted.
Singapore (SG)-based assignees are assignees who are Singapore residents. This includes local large enterprises (LLEs), local small-medium enterprises (SMEs), local start-ups, local institutions of higher learning (IHLs), public agencies, public research institutions (PRIs) and individuals (both Singaporeans and other nationalities) that reside in Singapore, as well as local subsidiaries of foreign enterprises (LSFEs).
Foreign-based assignees are assignees who are not Singapore residents. This includes foreign enterprises, foreign institutions of higher learning (IHLs), public agencies, public research institutions (PRIs) and individuals (both Singaporeans and other nationalities) that do not reside in Singapore.
Local subsidiaries of foreign enterprises (LSFE) in Singapore are foreign enterprises based in Singapore, including their regional headquarters.
For this report, local innovation actors refers to Singapore assignees minus local subsidiaries of foreign enterprises (LSFEs); foreign innovation actors are foreign-based assignees plus LSFE.

Where there is more than one assignee to a patent, we use fractional counting to assign the innovation to the joint assignees on an equal fraction basis. As the number of patents owned by individuals and foreign IHLs/other public organizations is relatively small, we exclude such patents from most of our analysis results presented below.

2 Patenting trends of different innovation actor groups

Annex Table A shows the historical growth trend of patents invented in Singapore from 1976 to 2020. As can be seen, the number of patents invented in Singapore has been steadily increasing over the years, from an average of fewer than 40 patents per year in the period 1986–1995, to more than 1,600 per year in the most recent period 2016–2020. As the "Singapore assignees" in this table actually include local subsidiaries of foreign firms, it overstates the share of local innovation actors. Even then, it is clear from Annex Table A that patenting outputs by foreign innovation actors in Singapore have overtaken those of local innovation actors since 2010.

To get a clearer picture of the changing contribution of local versus foreign innovation actors, we present in Figure 10 a breakdown into local and foreign innovation actors for the 2000–2020 period, by separating out the local subsidiaries from Singapore assignees and adding them to the foreign innovation actor group instead (see Table 4 for definitions). As can be seen in Figure 10, while the overall number of innovations in Singapore has increased at an annualized growth rate of 7.5 percent over the period 2000–2020, innovations by foreign innovators have grown much faster than innovations by local innovators (10.9 percent vs. 3.1 percent, respectively). As a result, the share of innovation in Singapore by foreign innovation actors has increased significantly over the period 2010–2020, rising from slightly less than half in the early 2000s to more than two-thirds toward the end of the 2020s (Figure 11).

Figure 12 provides a finer breakdown of the composition of innovation actor groups over the 20-year period. Among the local innovators, the share of local institutions of higher learning and public organizations has actually increased slightly, from 12 percent in 2000–2005 to 14 percent in 2016–2020; in contrast, the share of local private enterprises has declined dramatically, from over one third in 2000–2005 to 13.5 percent in 2016–2020, so that by the end of the 20-year period, local private enterprise patenting has dropped below that of local public organizations.

Figure 10 Growth trend of Singapore-invented patents by local vs. foreign ownership, 2000–2020

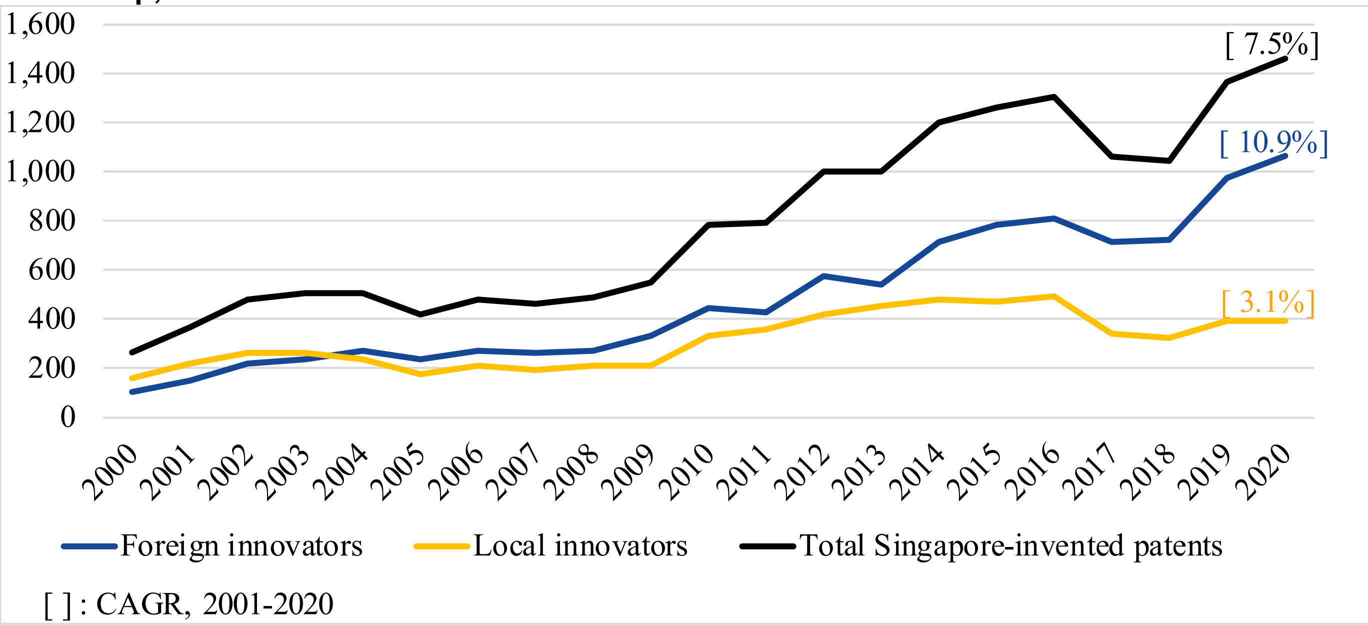


Figure 11 Share of Singapore-invented patents by local vs. foreign ownership, 2001–2020

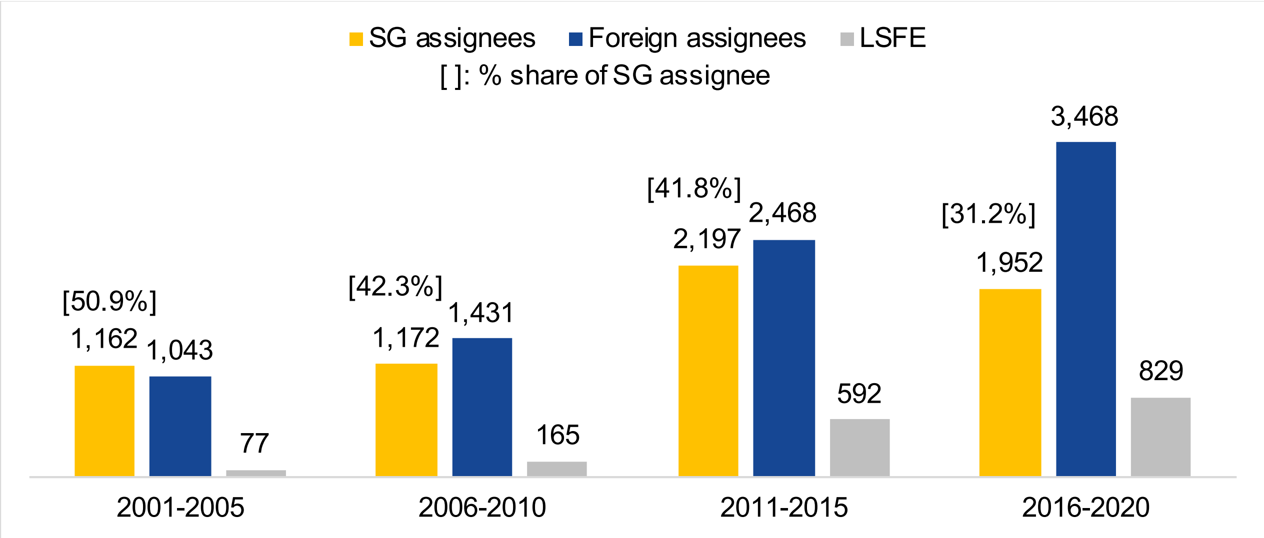
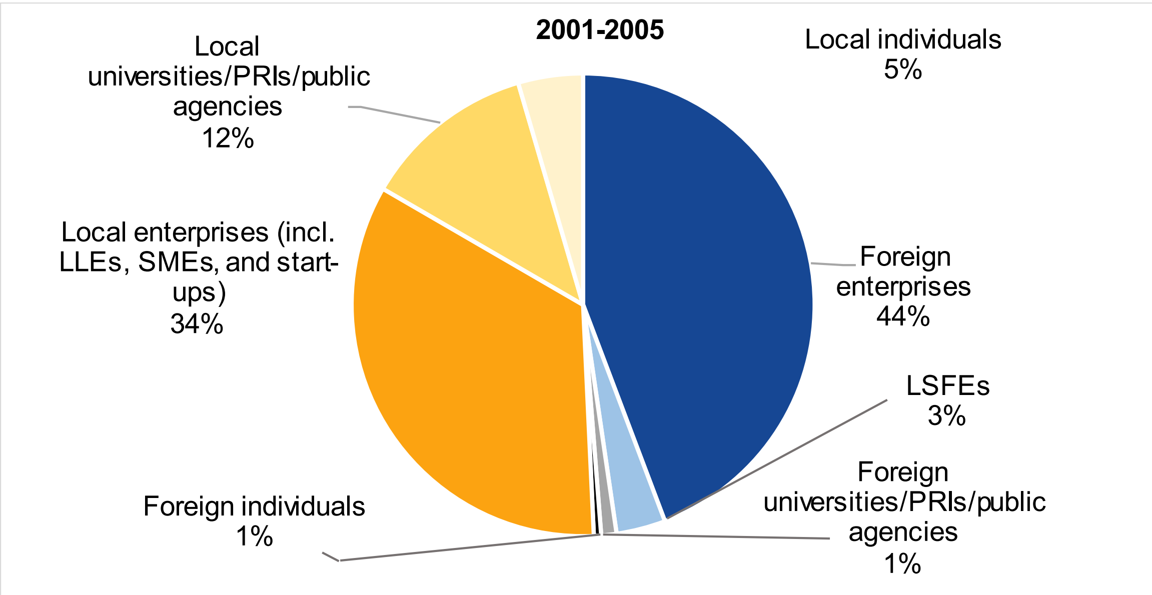
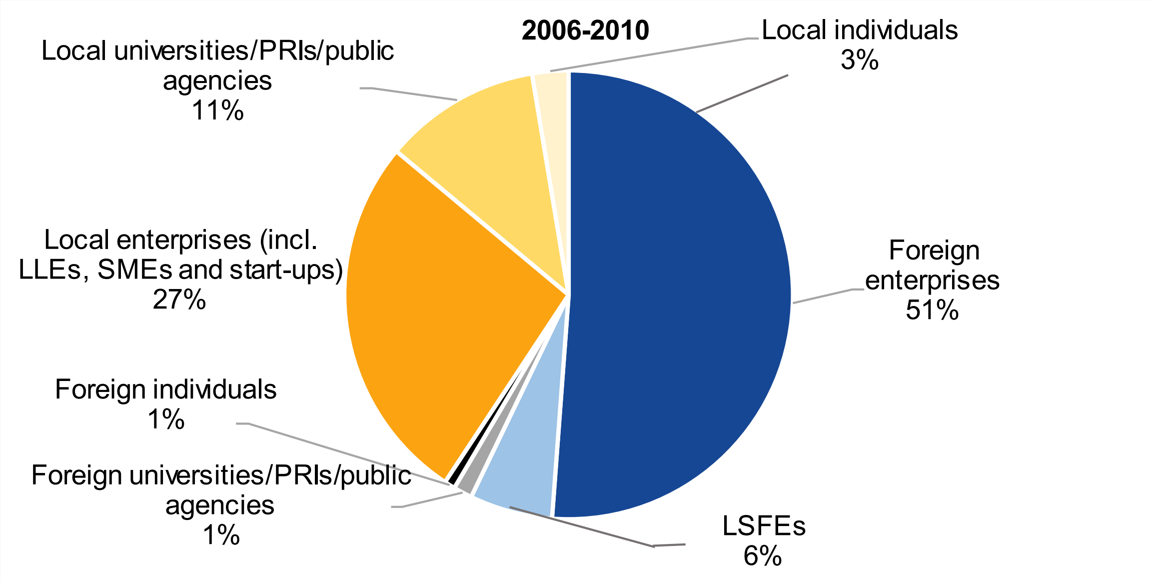
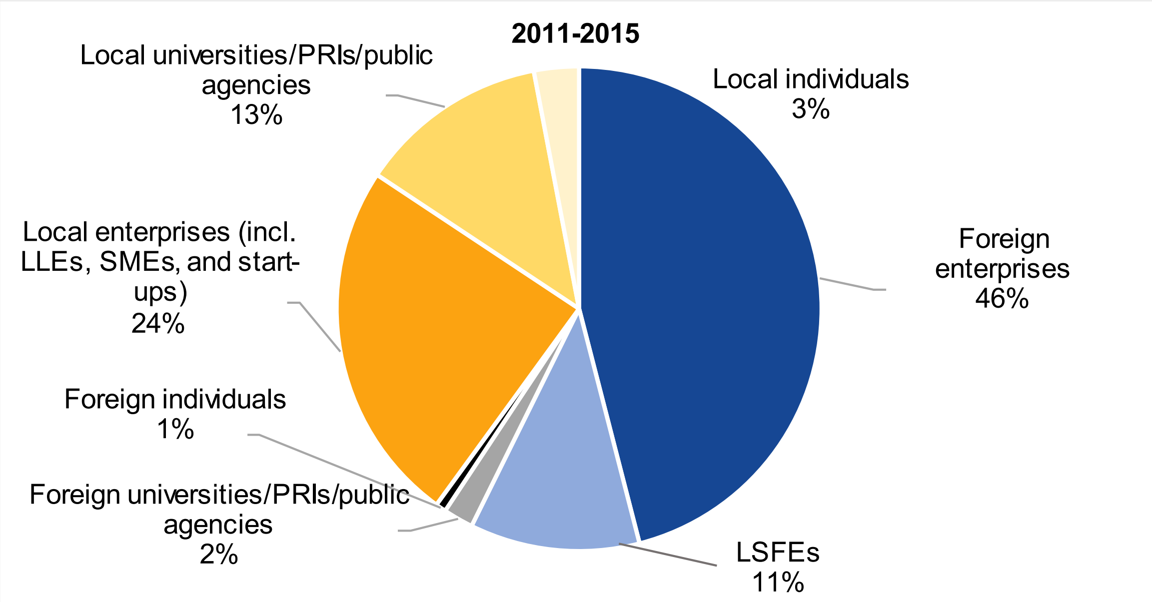
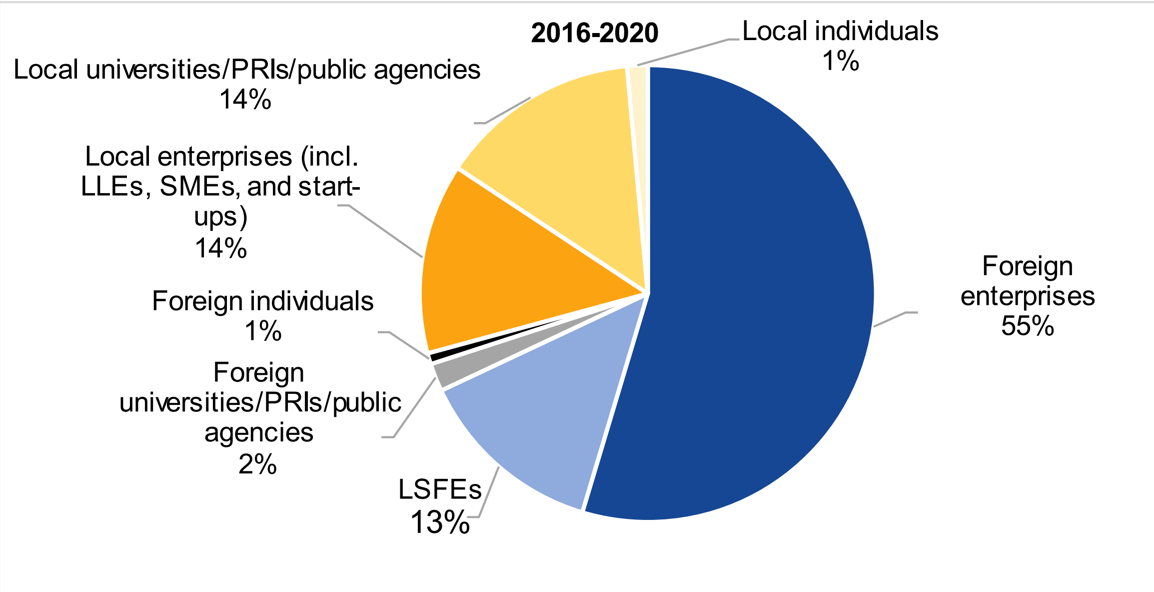


Figure 12 Composition of Singapore-invented patents by assignee types, 2001–2020




2006-2010
Local individuals 3%
Local universities/PRIs/public agencies 11%
Local enterprises (incl. LLEs, SMEs and start-ups) 27%
Foreign individuals 1%
Foreign universities/PRIs/public agencies 1%
LSFEs 6%
Foreign enterprises 51%


2011-2015
Local universities/PRIs/public agencies 13%
Local individuals 3%
Local enterprises (incl. LLEs, SMEs, and start-ups) 24%
Foreign individuals 1%
Foreign universities/PRIs/public agencies 2%
LSFEs 11%
Foreign enterprises 46%


2016-2020
Local individuals 1%
Local universities/PRIs/public agencies 14%
Local enterprises (incl. LLEs, SMEs, and start-ups) 14%
Foreign individuals 1%
Foreign universities/PRIs/public agencies 2%
LSFEs 13%
Foreign enterprises 55%

A further breakdown of patenting by local private enterprises shows that, while large local enterprises continued to generate more patents than SMEs/start-ups, their patenting numbers have shown a declining trend (notwithstanding an increase in the 2011–2015 period), while those for SMEs/start-ups have shown a steady increase (Figure 13). In contrast, both local IHLs and PRIs have exhibited steady growth in patenting over the entire 20-year period.

Figure 13 Patenting trends by local innovation actors, 2001–2020

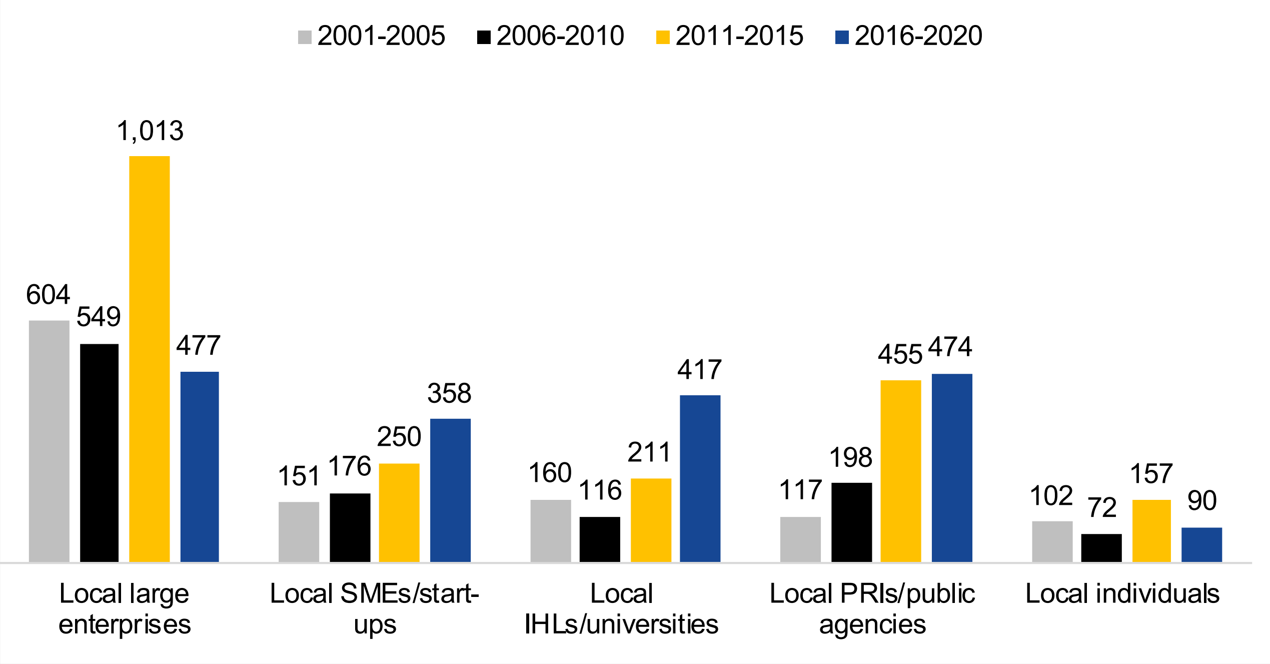
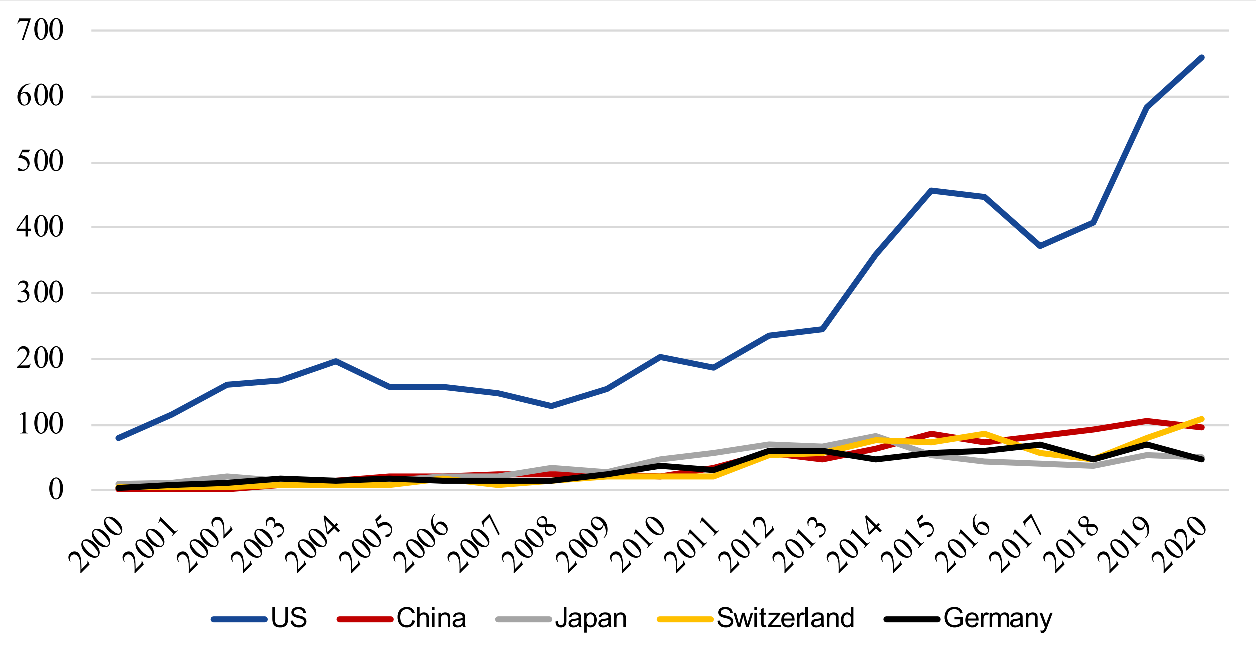


Figure 14 Top Five Countries of Origin of Foreign Owners of Patents Invented in Singapore, 2000–2020



Countries	Absolute number of patents (2001–2020)	CAGR (2001–2020)
US	5,529	9.6%
China	886	27.0%
Switzerland	774	8.4%
Japan	759	18.9%
Germany	706	11.3%

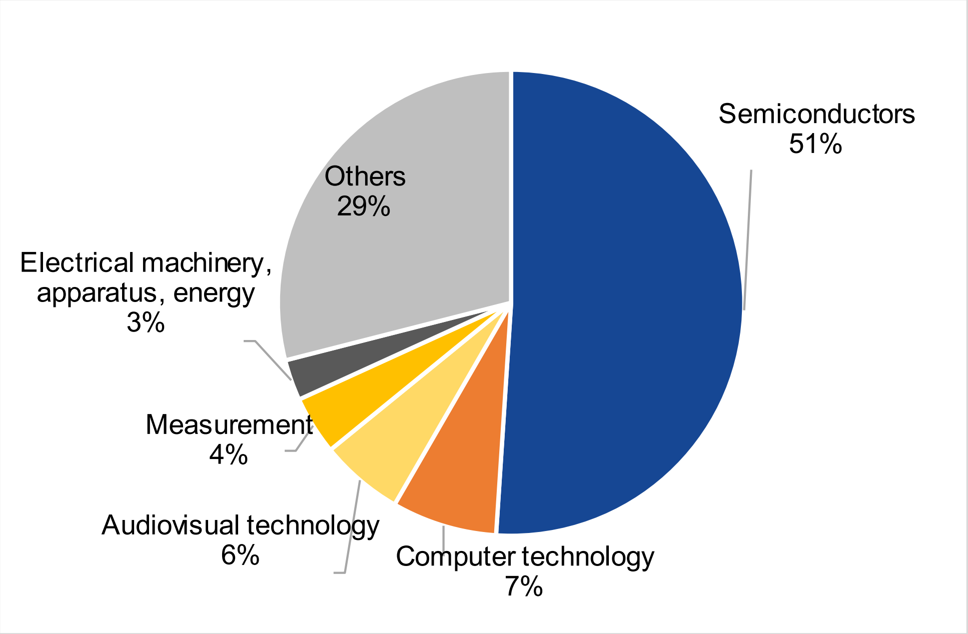
In terms of the national origins of the foreign owners of patents invented in Singapore, the US continues to be the largest, followed by China, Switzerland, Japan and Germany (Figure 14). However, the growth rates of patents owned by the US and Japan have been slower than those of China, Switzerland and Germany.

Among foreign-owned patents invented in Singapore, there appears to be a steady shift toward patents assigned to local subsidiaries, with the latter accounting for close to 20 percent of all foreign-owned patents in 2016–2020, versus just over 7 percent in 2000–2005 (computed from Figure 12). It is not clear what factors are driving this growing trend of assignment of patents owned by foreign enterprises to local subsidiaries in Singapore, but it may suggest Singapore's emerging regional IP management hub role for global multinational corporations.

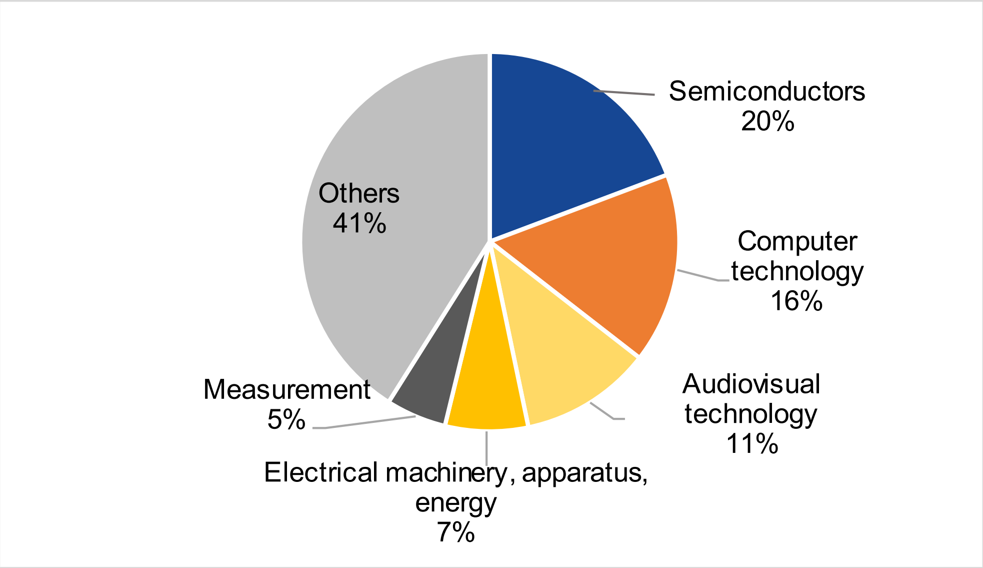
The different innovation actor groups also appear to differ in terms of technology field specializations. As can be seen from Figure 15, local enterprises are most highly concentrated by technology field, with semiconductors alone accounting for half of all patenting, and the share of the top three technology fields exceeding 63 percent (C3 = 0.63). In contrast, local IHLs/PRIs appear to be most diversified (C3 = 0.31), with foreign enterprises falling in between (C3 = 0.47). While semiconductor and computer technology rank among the top three technology fields for all three innovation actors, local IHLs/PRIs alone have significant biotechnology patenting. While this clearly reflects the significant focus on R&D into life sciences by the Singapore government, it also shows that this biotech push has not been taken up yet to any significant degree by private enterprises in Singapore, local or foreign.

Figure 15 Technology Field Specialization by Innovation Actors

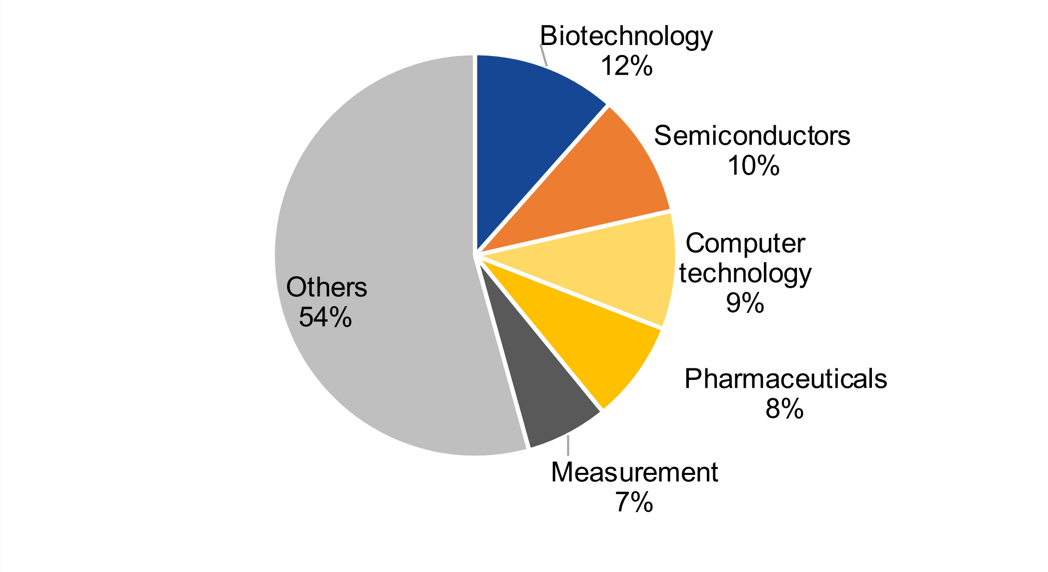
a. Innovative Innovative activities by local enterprises (incl. LLEs, SMEs and start-ups), 2001–2020



b. Innovative activities by foreign enterprises (incl. local subsidiaries), 2001–2020



c. Innovative activities by local IHLs, PRIs and public agencies, 2001–2020



Using the Herfindahl-Hirschman Index (HHI), a more refined measure of the degree of concentration by technology fields, we found that the patenting outputs by both local enterprises and IHLs/PRIs have become less concentrated by technology field over time, while the output of foreign enterprises has increased slightly (Table 5a). In addition, using the Difference Index, we found that the pattern of technology specialization of the local IHLs/PRIs has become more different from those of both the local enterprises and foreign enterprises over time, suggesting that the mismatch between public and private enterprise patenting in terms of technology fields has grown over time (Table 5b).

Table 5 Trend of Technology field concentration and specialization by innovation actor groups, 2000–2010 vs. 2011–2020

a. Concentration index (HHI) of the three innovation actor groups in terms of technology fields*

$$HHI = s_1^2 + s_2^2 + s_3^2 + \ldots s_n^2$$

Herfindahl-Hirschman Index	2001-2010	2011-2020
Foreign enterprise	896.5	960.9
Local enterprise	**2921.5**	**2307.7**
Local IHL/PRIs	702.9	622.2

b. Differences in technology field specialization* among innovation actor groups, as measured by difference index

Difference Index	2001-2010	2011-2020
Local enterprise-Local IHL/PRIs	**0.437**	**0.523**
Local enterprise-Foreign enterprise	0.385	0.320
Foreign enterprise-local IHL/PRIs	0.316	0.422

* Measured using the 35 technology field classifications of WIPO

While there is a growing trend of patenting that draws on prior knowledge from multiple technology fields, the incidence of such “complex” innovation remains low, and the majority of patenting continues to cite prior patents in the same technology field. As such, the significant (and growing) mismatch between the technology field specialization of IHLs/PRIs and private enterprises in Singapore could imply a barrier for existing private enterprises in Singapore to utilize and build on the technological innovations coming out of the local IHLs/PRIs. This leads to the broader issue of knowledge interactions among innovation actors – to what extent are the different innovation actors collaborating, and to what extent are the innovation actors drawing on the innovations invented in Singapore to generate new innovations?

3 Knowledge interactions among innovation actor groups

By utilizing the data contained in patent documents on coinventorship, coassigneeship and backward-citation links, we can develop a number of proxy measures of the pattern of knowledge interactions among innovation actors in Singapore, and how these interaction patterns have changed over time.

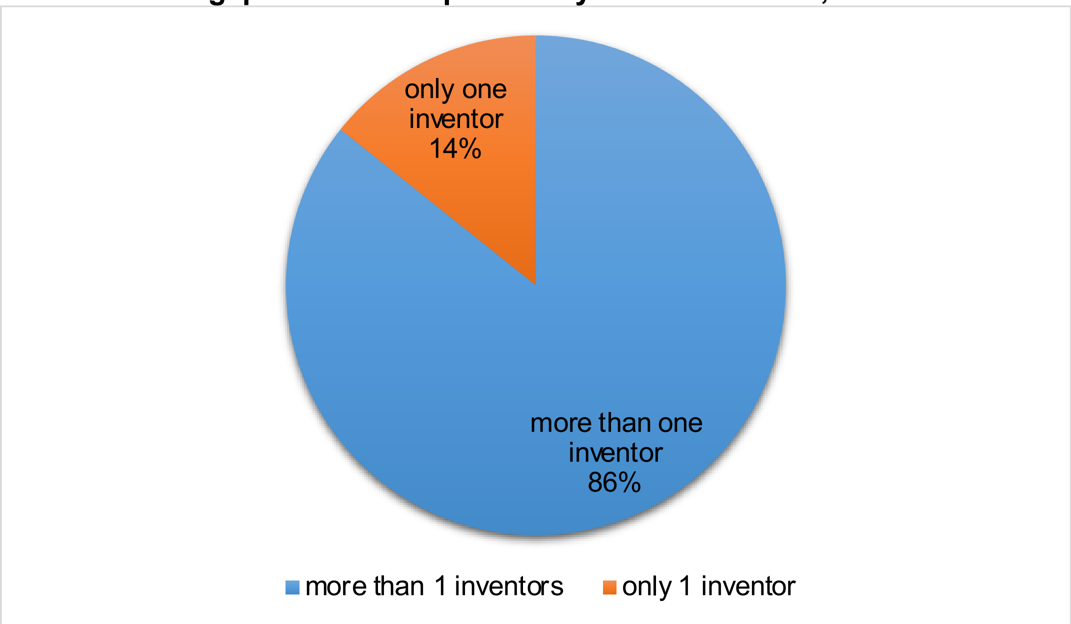
3.1 Geographical pattern of cross-border collaboration in innovation (as measured by locations of coinventors)

As can be seen from Figure 16, 86 percent of the Singapore-invented patents granted in the period 2000–2020 have more than one inventor. Among these coinvented patents, nearly half (49 percent) involved cross-border collaborations. The share of coinvented patents involving coinventor(s) located overseas has been steadily increasing over the years, from 42 percent in the period 2000–2005 to 54 percent in the period 2016–2020 (Figure 17).

A geographical breakdown of the country of location of overseas coinventors shows the US remains the largest foreign country for coinventorship, although its dominance has declined from 55 percent in 2000–2010 to 48 percent in 2011–2020, while the share of the next two largest countries (China and Japan) have both increased (Figure 18). Interestingly, Russia has emerged as the fifth-largest country of location of foreign coinventors in the last decade, while Malaysia's share has declined significantly from 9 percent in 2000–2010 to only 3 percent in 2010–2020.

Figure 16 Coinventorship of patents in Singapore, 2001–2020

a. Share of Singapore-invented patents by no. of inventors, 2001–2020



b. Share of co-invented patents by inventor types, 2001–2020

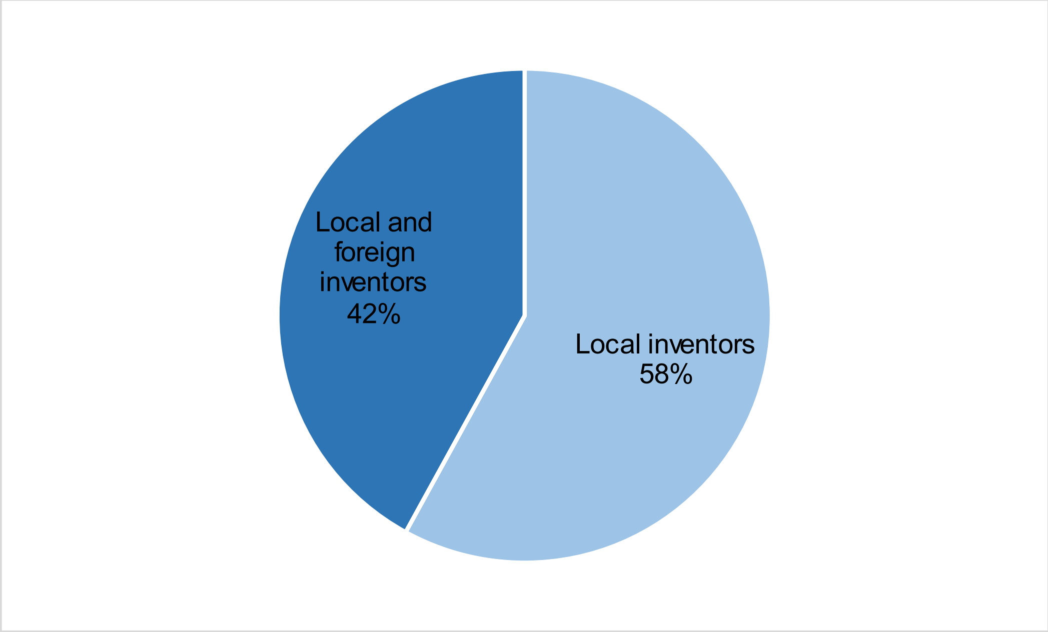
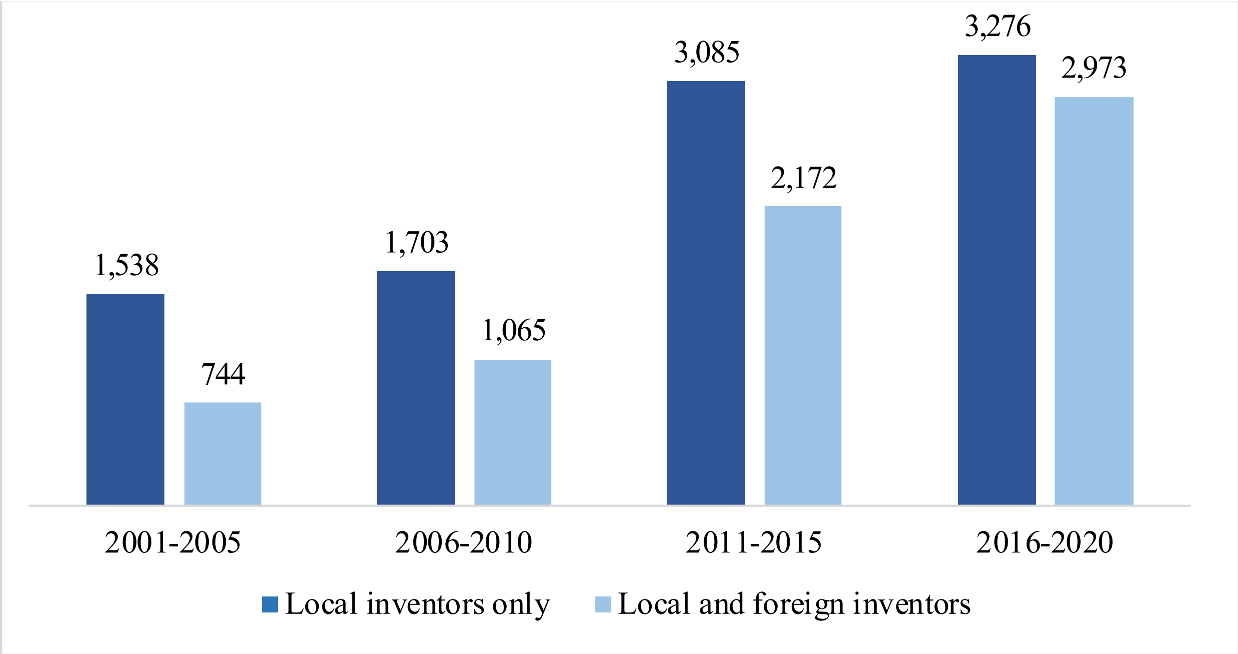


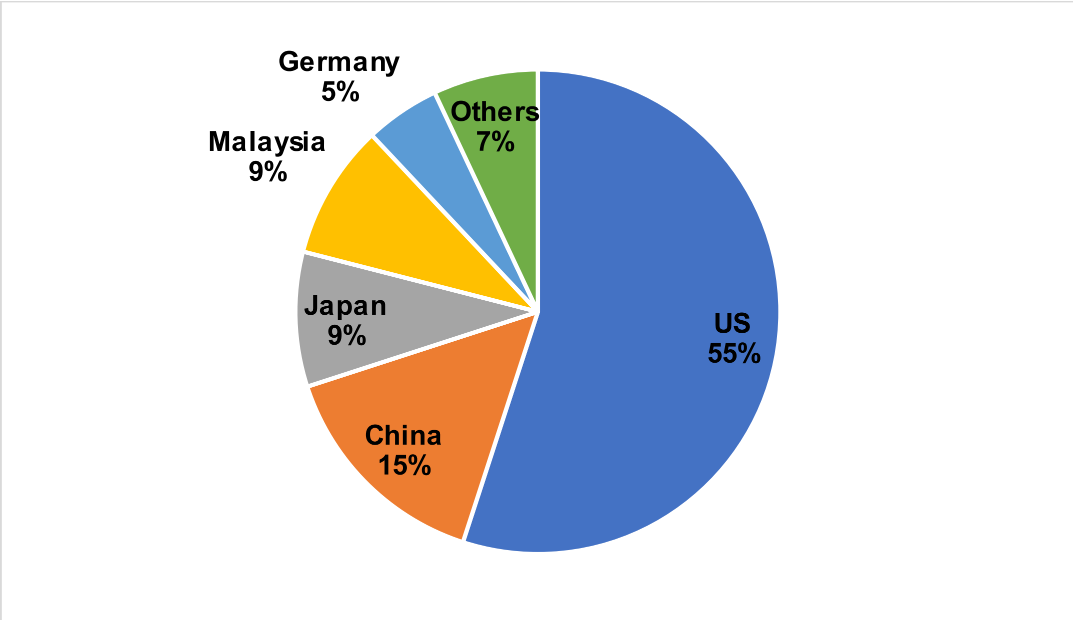
Figure 17 Trend of patenting in Singapore involving cross-border coinventorship, 2000–2020



A more detailed breakdown of overseas coinventor location according to the Global Innovation Hotspots classification by WIPO confirms the surprising emergence of Moscow in Russia as the top hotspot location for coinventorship, followed by Hsinchu in Taiwan Province of China, San Jose in the US and Osaka and Kanagawa in Japan (Figure 19). Except for three locations in Malaysia (Johor Baru, Penang and Petaling Jaya), no other locations in ASEAN appear among the top 51 coinventorship hotspots, suggesting that innovation links of Singaporean innovators with the rest of ASEAN remain rather weak. In addition, Singapore appears to have only moderate innovation links with a number of leading regional innovation hotspots in Asia that are close to Singapore – Bangalore and Hong Kong ranked only 21st and 22nd, respectively, while Shenzhen, another major innovation hotspot in the Greater Bay Area of South China, is outside the top 51 locations altogether.

Figure 18 Country of location of foreign coinventors, 2000–2020

a. Percentage share of coinvented patents, 2001–2010



b. Percentage share of co-invented patents, 2011–2020

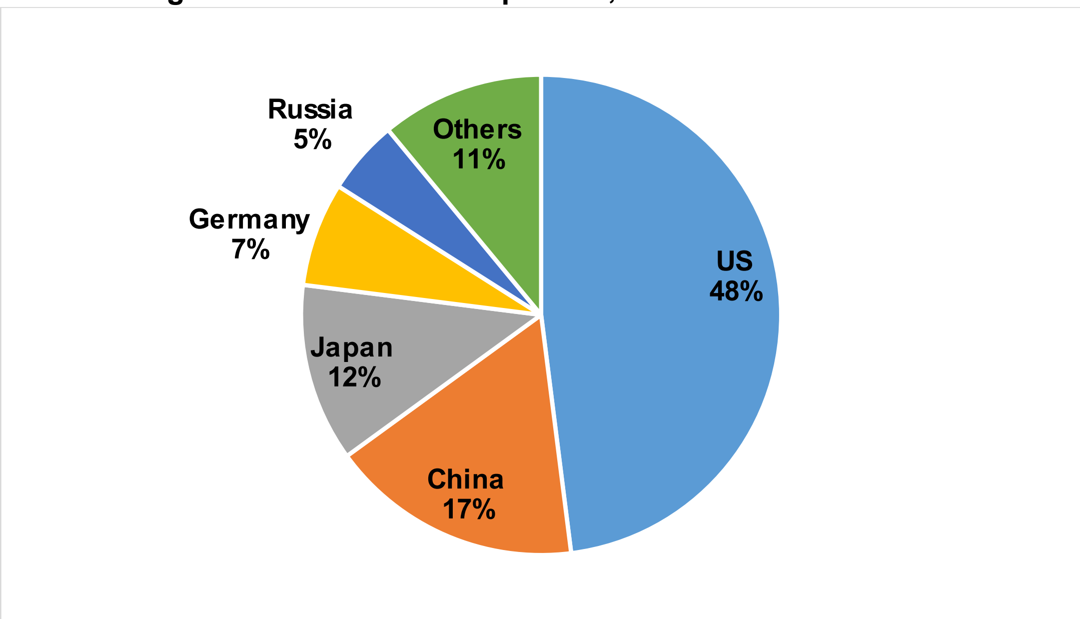


Figure 19 Top global hotspot locations of foreign coinventors, 2000–2020

No.	Year	2001–2010	2011–2020	Grand total
1	Moscow	112	645	757
2	Hsinchu	118	414	532
3	San Jose	111	296	407
4	Osaka	14	335	349
5	Kanagawa	24	266	290
6	Shanghai	52	195	247
7	Tokyo	65	169	234
8	Beijing	24	198	222
9	San Francisco	88	102	190
10	Houston	73	134	207
11	San Diego	22	169	191
12	Taipei	60	118	178
13	Palo Alto	36	97	133
14	Cambridge	16	120	136
15	Fremont	28	106	134
16	Zhubei	0	135	135
17	Johor Bahru	62	68	130
18	Seoul	34	95	129
19	Sunnyvale	46	82	128
20	Austin	36	88	124
21	Bangalore	7	99	106
22	Hong Kong	32	61	93
23	Yokohama	37	52	89
24	Cupertino	32	57	89
25	Pleasanton	8	76	84
26	New York	17	66	83
27	London	10	73	83
28	Santa Clara	25	55	80
29	Chiba	17	61	78
30	Irvine	28	51	79
31	Boise	21	58	79
32	Eindhoven	20	58	78
33	Nara	4	63	67
34	Gyeonggi-do	8	57	65
35	Aberdeen	21	39	60
36	Munich	12	51	63
37	Kaohsiung	8	53	61
38	Mannheim	1	54	55
39	Penang	28	25	53
40	Mandaluyong	19	34	53
41	Mississauga	25	27	52
42	Seongnam	1	50	51
43	Petaling Jaya	31	18	49
44	Seattle	3	46	49
45	Orlando	44	5	49
46	Mountain View	6	42	48
47	Nampa	15	34	49
48	Tainan	1	47	48
49	Chandler	20	27	47
50	San Mateo	5	40	45
51	Taoyuan	9	36	45

3.2 Collaboration pattern among innovation actor groups (as measured by coassigneeships)

Inter-organizational collaboration in innovation often leads to coownership of the intellectual properties generated; consequently, a measure of the extent of innovation collaboration among different innovation actors is the incidence of coassigneeship, where the ownership rights to a patent have been assigned to multiple assignees.

Table 6 shows the pattern of coassigneeship links within and across the four types of innovation actors in Singapore – local enterprises, local IHLs/PRIs, foreign enterprises (incl their local subsidiaries in Singapore), and foreign IHLs/PRIs – over the two time periods of 2000–2010 and 2011–2020, respectively. In the first time period, 2000–2010, the largest incidence of inter-organizational collaboration appears to be among the foreign enterprises, followed by collaborations between foreign and local enterprises, and third between local enterprises and local IHLs/PRIs. In the more recent time period, 2011–2020, the number of such inter-organizational collaborations has tripled, but collaborations among foreign enterprises still remain the most frequent. Inter-organizational collaborations involving local IHls/PRIs have also increased substantially, particularly with foreign enterprises as well as with other IHLs/PRIs, both local and foreign. However, local IHLs/PRIs' collaborations with local enterprises have increased only modestly. Collaborations between local enterprises and foreign enterprises have stagnated, while collaborations among local enterprises themselves have remained low.

Table 6 Coassigneeship links among different innovation actor groups, 2000–2010 vs. 2011–2020

☐ Mirrored results [ ] : Top 3 pairs of coassignees

Cumulative no. of patents (2000–2010)	Foreign enterprises (incl. subsidiaries)	Foreign universities/PRIs/public agencies	Local enterprises	Local universities/IHLs/PRIs/public agencies	Total
Foreign enterprises (incl. subsidiaries)	52 [1]	1	49 [2]	29	131
Foreign universities/PRIs/ public agencies		6	1	3	11
Local enterprises			3	31 [3]	84
Local universities/IHLs/PRIs/public agencies				25	88

Cumulative no. of patents (2000–2010)	Foreign enterprises (incl. subsidiaries)	Foreign universities/PRIs/public agencies	Local enterprises	Local universities/IHLs/PRIs/public agencies	Total
Foreign enterprises (incl. subsidiaries)	176 [1]	22	50	120 [2]	368
Foreign universities/PRIs/ public agencies		17	2	70	111
Local enterprises			10	53	115
Local universities/IHLs/PRIs/public agencies				82 [3]	325

3.3 Knowledge links among innovation actor groups (as measured by backward-citation links of patents)

The backward-citations of patents provide information on the "prior arts" upon which the patent inventions are based or developed from. While such prior arts represent only a partial source of knowledge for the new patented invention, they can be used to trace at least part of the knowledge flows between the citing and cited inventions. By examining the assignees of the patents cited by the innovation actors' patent inventions in Singapore, we can trace the knowledge links between the organizations owning the citing inventions and the organizations owning the cited, prior inventions.

Table 7 shows the overall distribution of assignees owning the patents cited by patents invented in Singapore granted in the period 2011–2020. As can be seen, only 10 percent of the backward-citations were to prior patents invented in Singapore. While this represents an increase from 6.6 percent for the period 1976–2001 in a prior study (Wong and Singh, 2008), it remains true that the knowledge sources for Singapore's patents are from inventions outside Singapore. Among this 10 percent of cited prior patents that were invented in Singapore, over 77 percent were owned by local enterprises, with less than 2 percent being patents owned by local IHLs/PRIs, suggesting that local IHLs/PRIs remain a negligible source of patented knowledge upon which new patents are generated in Singapore.

Table 7 Assignees of patents cited by Singapore-invented patents, 2011–2020

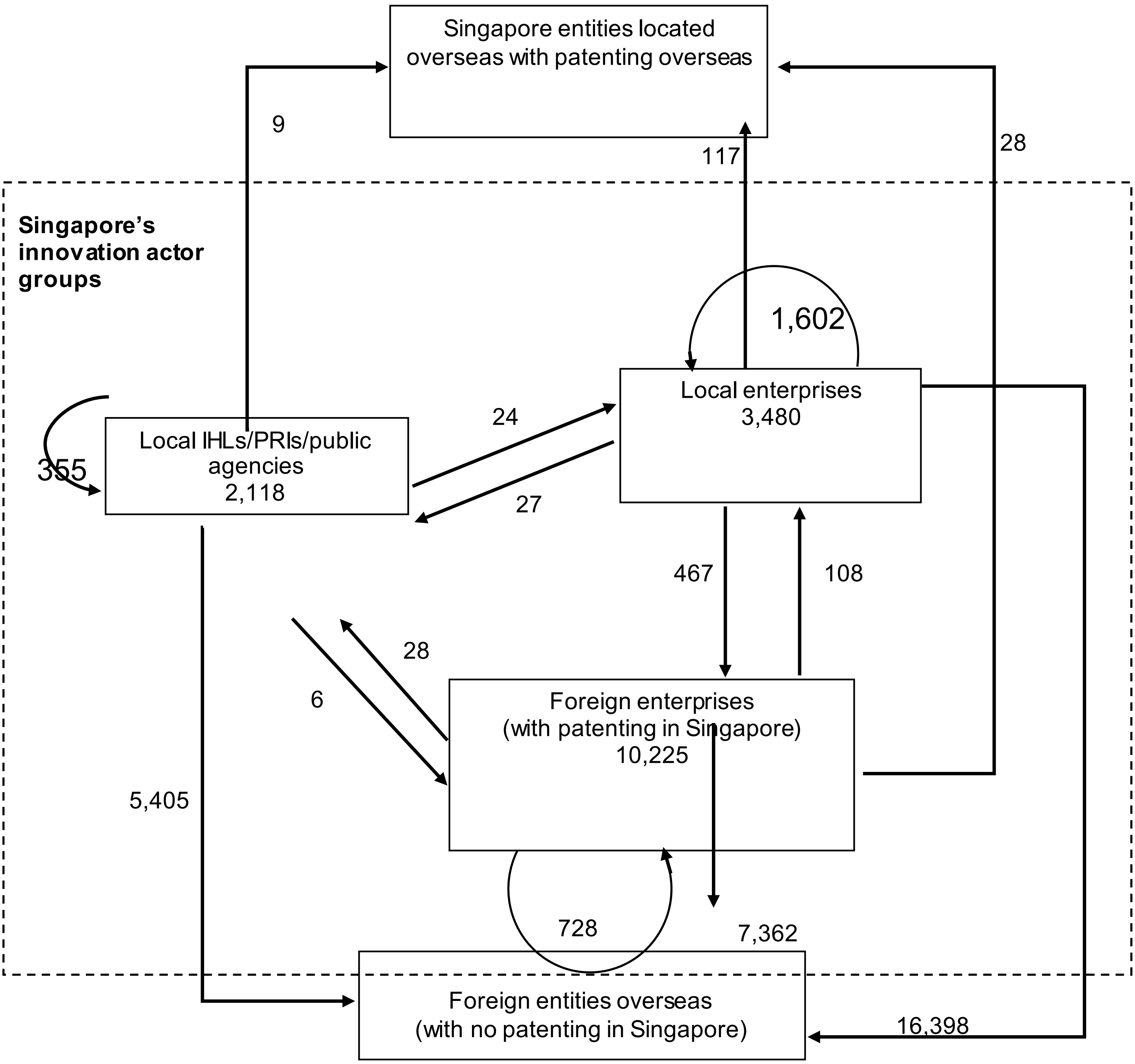
Backward-cited patents	2011–2015	(%)	2016–2020	(%)
With at least one inventor from Singapore	2,315	10	1,995	10
At least one SG assignee	1,849	8	1,778	9
No SG assignee	466	2	217	1
No inventors from SG	20,378	90	18,349	90
At least one SG assignee	425	2	409	2
No SG assignee	19,953	88	17,940	88
Grand total	**22,693**	**100**	**20,344**	**100**

Backward-cited patents with at least one SG assignee	2011–2015	(%)	2016–2020	(%)
Local large enterprises (LLEs)	1,307	71	1,123	63
SMEs/start-ups	172	9	197	11
Local IHLs/PRIs/public agencies	19	1	50	3
Individuals	291	16	330	19
Others (mainly local subsidiaries of foreign firms)	60	3	79	4
Grand total	**1,849**	**100**	**1,778**	**100**

Figure 20 provides a more detailed breakdown of the backward-citation links among the various innovation actors in Singapore over the period 2000–2020. As can be seen, the bulk of the citation links by the three groups of Singapore-based innovation actors (local enterprises, local IHLs/PRIs and foreign-owned enterprises with patenting activities in Singapore) were to non–Singapore-invented patents owned by foreign entities. Interestingly, a much smaller but growing number of backward-citation links went to patents invented overseas but owned by known Singaporean enterprises located overseas, suggesting a nascent trend of internationalization of innovation activities by Singaporean enterprises, and the flow of knowledge from such overseas innovation activities back to Singapore.

For the much lower level of citation links within Singapore, the strongest links were links *within* each innovation actor groups (e.g., local enterprises making self-citations to patents they already owned, or citing patents invented by other local enterprises in Singapore). In contrast, the citation links *between* innovation actor groups were generally quite weak, especially the links between the local IHLs/PRIs and both local and foreign enterprises. Local enterprises and local IHLs/PRIs also cited patents of foreign enterprises in Singapore four times more than vice versa.

Figure 20 Backward-citation links among innovation actor groups, 2000–2020



Note:
(1) Intra-group citation links include self-citations.
(2) Numbers are based on factional counts, rounded to nearest number.
(3) Excludes patents by individuals, and cited patents by individuals.

4 Summary observations and suggested areas for future research

The overall picture that emerged from this more in-depth analysis of the different innovation actor groups using patenting data is largely consistent with the broad development trends highlighted in Part A of this report. In addition, this innovation actor group analysis provides a number of more fine-grained insights that identify useful areas for future research. In particular, the following can be highlighted:

- innovation activities by foreign enterprises, as reflected in patenting outputs, are growing faster and now account for significantly more than local actors (local enterprises and local IHLs/PRIs). The rapid growth of innovation activities by foreign enterprises in Singapore, especially after 2010, appears to be in line with the goal of the Singapore government's IP Hub Masterplan 2013 (Ministry of Law, 2013) to make Singapore a leading global hub for innovation activities by global MNCs. This strategy of attracting more innovation activities by foreign enterprises to Singapore is further reaffirmed by the more recent Singapore IP Strategy 2030 (Intellectual Property Office of Singapore, 2021). Further research is recommended to examine the extent to which the specific policies and programs implemented through the IP Hub Masterplan have indeed contributed to the rapid growth of innovation outputs by foreign enterprises in Singapore in recent years.

- The growing role of foreign enterprises in Singapore's patenting outputs in recent years has occurred to a greater extent than the growth of their R&D expenditure would suggest. This higher patenting-to-R&D ratio for foreign enterprises in recent years could reflect either higher R&D productivity, or a stronger commercial orientation of their R&D activities compared to local firms and local IHLs/PRIs. Further research is recommended to examine the determinants of this R&D to patenting output differentials among the innovation actor groups in Singapore.

- While affirming the significant extent and diversity of international linkages between Singapore-based innovation actors and innovation actors overseas, our geographical analysis of the key coinvention hotspots reveals a surprisingly strong link to Russia (Moscow), while showing weak links with ASEAN and only very moderate links with a number of leading hotspots in our region – the Greater Bay Area (GBA) of China, and India. Further research is recommended to examine the factors that could expand Singapore's innovation links with them. An international benchmarking analysis could also be conducted to compare Singapore's international innovation linkage pattern with other leading innovation hotspots in the region, for example, Shenzhen, Bangalore and Seoul.

- The innovation linkages of the innovation actor groups in Singapore, particularly the local IHLs/PRIs and local enterprises, as measured by innovation collaboration (patent coassigneeship) and knowledge flows (backward-citations), remain weak.

- Further research is recommended to examine the impediments to greater links among them, and the extent to which the significant mismatch between the technology fields of innovation targeted by IHLs/PRIs and local enterprises that we found could be a contributing factor.

- As revealed by Annex Figure A, the number of patents invented outside Singapore but granted to Singapore-based assignees has increased very significantly, from 105 over 1976–2000 to almost 2,000 over 2001–2010, and more than 9,300 over 2011–2020; indeed, in the last five years, in the period 2016–2020, the number of overseas patents granted to Singapore-based assignees has reached 81 percent of the number of patents invented in Singapore. Further research is recommended to examine this rapid innovation internationalization phenomenon – is it driven largely by local subsidiaries of foreign enterprises (LSFEs) in Singapore, which would suggest a significant IP management hub role by foreign enterprises located in Singapore, or are local enterprises increasingly moving their innovation activities overseas as well? And where are these overseas innovation activities located – are they globally distributed, or regionally clustered?

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Annex

Figure A growth in patents issued by the USPTO to Singapore inventors and assignees, 1976–2020

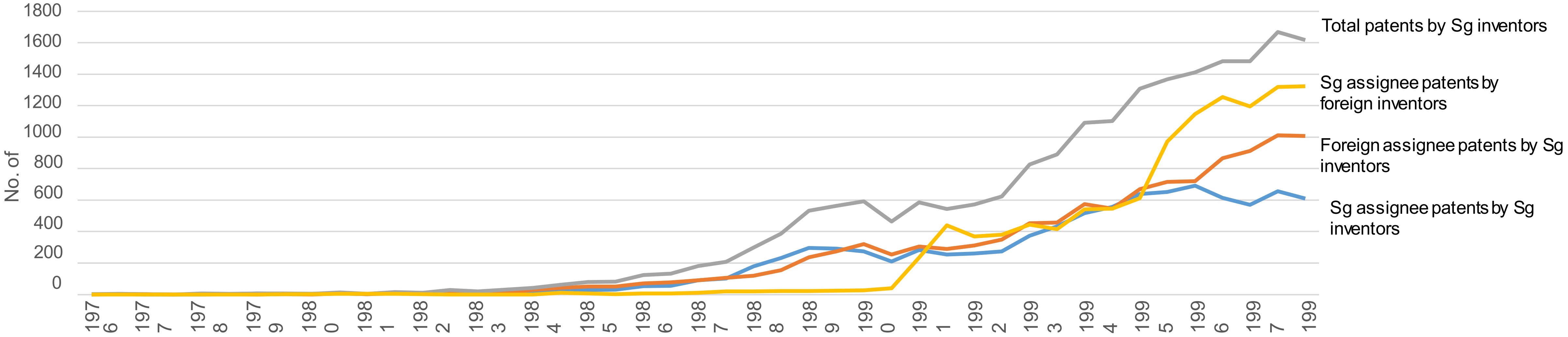

Table A1 Patent applications at the USPTO by Singapore based inventors and applicants, 1976–2020

	1976–1985	1986–1995	1996–2000	2001–2005	2006–2010	2011–2015	2016–2020	Total
	Patents by Singapore-based inventors							
Singapore assignee	30	148	480	1,303	1,443	2,797	3,143	9,344
Foreign assignee	22	227	463	1,239	1,708	2,963	4,518	11,140
Total	*52*	*375*	*943*	*2,542*	*3,151*	5,760	7,661	20,484
	Patents by inventors located overseas but assigned to Singaporean organizations							
	11	30	64	134	1,865	3,087	6,241	11,432
Total	*63*	*405*	*1,007*	*2,676*	*5,016*	*8,847*	*13,902*	*31,916*

Source: Calculated from USPTO data

Table A2 Top 50 assignee for Singapore invented patents, 2000–2019

2000–2019					
S/N	Company name	Total patents	S/N	Company name	Total patents
1	AGENCY FOR SCIENCE, TECHNOLOGY AND RESEARCH*	923	26	3M INNOVATIVE PROPERTIES COMPANY	74
2	STATS CHIPPAC LTD.	626	27	VESTAS WIND SYSTEMS A/S	73
3	CHARTERED SEMICONDUCTOR MANUFACTURING LTD.	613	28	MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD	67
4	GLOBALFOUNDRIES SINGAPORE PTE. LTD.	518	29	APPLIED MATERIALS, INC.	59
5	SEAGATE TECHNOLOGY LLC	472	30	DELL PRODUCTS L.P.	59
6	NATIONAL UNIVERSITY OF SINGAPORE*	409	31	AVAGO TECHNOLOGIES GENERAL IP (SINGAPORE) PTE. LTD.	58
7	NANYANG TECHNOLOGICAL UNIVERSITY*	371	32	ST ASSEMBLY TEST SERVICES PTE LTD	58
8	STMICROELECTRONICS ASIA PACIFIC PTE LTD	290	33	DATAMAX-O'NEIL CORPORATION	57
9	MICRON TECHNOLOGY, INC.	223	34	INSTITUTE OF MICROELECTRONICS*	56
10	HEWLETT-PACKARD DEVELOPMENT COMPANY, L.P.	215	35	SUN PATENT TRUST	55
11	INTERNATIONAL BUSINESS MACHINES CORPORATION	215	36	MASSACHUSETTS INSTITUTE OF TECHNOLOGY	54
12	UNITED MICROELECTRONICS CORP.	212	37	BASF SE	51
13	INFINEON TECHNOLOGIES AG	178	38	RAZER (ASIA-PACIFIC) PTE. LTD.**	51
14	HALLIBURTON ENERGY SERVICES INC.	162	39	SONY CORPORATION	47
15	MARVELL INTERNATIONAL LTD.	153	40	UNITED TEST AND ASSEMBLY CENTER LTD.	46
16	TAIWAN SEMICONDUCTOR MANUFACTURING COMPANY, LTD.	152	41	TEMASEK LIFE SCIENCES LABORATORY LIMITED*	45
17	PANASONIC CORPORATION	121	42	PANASONIC INTELLECTUAL PROPERTY CORPORATION OF AMERICA	43
18	CREATIVE TECHNOLOGY LTD**	119	43	ROLLS-ROYCE PLC	42
19	KONINKLIJKE PHILIPS ELECTRONICS N.V.	113	44	FINISAR CORPORATION	41
20	STMICROELECTRONICS PTE LTD	99	45	MEDIATEK SINGAPORE PTE. LTD.	41
21	BRIDGE SEMICONDUCTOR CORPORATION	98	46	SIEMENS MEDICAL INSTRUMENTS PTE. LTD.	40
22	ASM TECHNOLOGY SINGAPORE PTE LTD	95	47	ADVANCED MICRO DEVICES INC	39
23	THE PROCTER & GAMBLE COMPANY	91	48	PARALLELS INTERNATIONAL GMBH	39
24	AVAGO TECHNOLOGIES ECBU IP (SINGAPORE) PTE. LTD.	88	49	YOKOGAWA ELECTRIC CORPORATION	39
25	INFINEON TECHNOLOGIES AUSTRIA AG	78	50	ACRONIS INTERNATIONAL GBMH	38

Notes: *Local public, **Local enterprises.